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PHYSICAL LABORATORY MANUAL

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PHYSICAL

LABORATORY MANUAL

FOR USE IN

SCHOOLS AND COLLEGES

BY

H. N. CHUTE, M.S.

AUTHOR OF "PRACTICAL PHYSICS," ETC., AND TEACHER OF PHYSICS
IN THE ANN ARBOR HIGH SCHOOL

BOSTON, U.S.A.
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PREFACE.

It is generally conceded by science teachers that physics should "be taught by a combination of laboratory work, text-book, and thorough didactic instruction, carried on conjointly." The attempt to combine practical work and the exposition of principles in the same book has not proved a success in the past; and in view of the difficulties to be overcome, it is very doubtful if it can be satisfactorily accomplished. Before a student is fitted for experimental investigation he must have a clearly defined idea of what it is that he is to do, and how he is to do it; what he is to expect, what errors are to be guarded against, and how he is to use the results obtained. This requires that he should come to the laboratory well grounded in the first principles of physics as presented in some elementary treatise on the subject, and well read, especially on the subject that he is to investigate, both as to mode of conducting the work, and manner of observing. It is not necessary, however, that the student should traverse the entire subject of physics before entering upon laboratory practice; but he should be kept in his class-work well ahead of the subject forming the basis of his laboratory experiments. To do otherwise is to expect him to rediscover the laws of physics, notwithstanding his lack of skill in manipulation, his ignorance of methods of experimenting, and his inability to make proper observations from not knowing what to look for, when to look, and where to look.

The educational value of practical physics does not lie in the so-called discovery of laws, nor in the experimental demonstration of principles. Indeed, it is very doubtful if the small number of laws the student would be likely to discover would adequately compensate for the large outlay of time that would be necessary, owing to his defective powers of observation, and lack of skill in manipulation. But, rather, its value is to be found in the training it gives in attention to details, in the cultivation of accuracy in observing the smallest changes, in the formation of systematic methods of working, in developing the ability to reason back to a general law from a particular set of observations, and in cultivating habits of precise expression of ideas and principles on the pages of the note-book.

Hence it would seem that the work of the laboratory should be largely quantitative in character, if all these advantages are to be gained by its introduction. Accordingly, the author has attempted to provide such a set of problems judiciously distributed over the several divisions of physics, hoping thereby to touch the subject at most of its chief points, and at the same time keep within the mental grasp of students of secondary schools who are expected to pursue this subject.

Recognizing that comparatively few schools have adopted laboratory methods on account of the difficulty of obtaining apparatus of proper design at reasonable expense, special pains have been taken in selecting problems that could be solved by the aid of simple and inexpensive apparatus. Many of the instruments are not beyond the skill of the average mechanic, and not a few are within the constructive ability of many a bright boy.

In the report of the Committee of Ten appointed by the National Educational Association in 1892 occurs the following: "To give good instruction in the sciences requires of the teacher more work than to give good instruction in mathematics or the languages, and the sooner this fact is recognized by those who have the management of schools the better for all concerned. The science teacher must regularly spend much time in collecting materials, preparing experiments, and keeping collections in order; and this indispensable labor should be allowed for in programmes and salaries."

In view of the fact that school officials very rarely make any such allowances as referred to in this report, the science teacher in our public schools is the most overworked person on the staff, and finds it impossible to give the students in the laboratory such instruction and assistance as they must have, in order that the work may yield that training and discipline it is so well calculated to give. Accordingly, the instructions in manipulation of apparatus are made unusually full, and an attempt has been made to anticipate all the important difficulties that are likely to arise. It is hoped that these have been in a large measure accomplished by the liberal introduction of cuts, suggestions, and numerical examples taken from students' note-books. Special attention has been given to the important subject of tabulating and working out results, and deriving from them proper conclusions. The numerical examples will indicate to the beginner how high a degree of accuracy may be expected from the quality of apparatus described, when carefully and intelligently manipulated.

Several valuable appendices conclude the volume, giving aid in the construction and repairing of apparatus, and furnishing a sufficiently complete list of the more important Physical Constants, accompanied by explanations when necessary.

Special acknowledgments are due to THE FRANKLIN EDUCATIONAL Co. of Boston, GAGE & SON of Boston, QUEEN & Co. of Philadelphia, RITCHIE & SONS of Brookline, Mass., and GOODNOW & WIGHTMAN of Boston, for the use of a number of illustrations.

The thanks of the author are due to a number of friends who have helped in the revision of the proof-sheets. Of these he would mention DR. J. MONTGOMERY of the Ann Arbor High School; F. A. OSBORNE, assistant in the physical laboratory; GEO. L. CHANDLER, High School, Newton, Mass.; PRESTON SMITH, High School, Brockton, Mass.; and J. C. PACKARD, High School, Brookline, Mass. Although they have contributed in no small degree to the accuracy of the book, yet they are in no wise responsible for its defects.

H. N. CHUTE.

ANN ARBOR HIGH SCHOOL LABORATORY,
August, 1894.

TO THE TEACHER.

I. THE PHYSICAL LABORATORY.

The Room. — Where a separate room can be provided for experimental work in physics, it should be large and well ventilated, and should have a southern exposure. It should either be provided with tight cases for storing apparatus, or there should open off from it a room provided with suitable cases. There should be some provision made for darkening the windows, such as folding-blinds, or frames covered with opaque cloth.

In case that a separate room cannot be provided for a laboratory, then use the recitation-room by placing tables in the back part, rather than omit from the school curriculum this important kind of training. It is now conceded by all wide-awake teachers that a student should be brought in actual contact with the phenomena to be studied by him, if he would know Nature and her laws, and receive from their study mental strength. It was Maxwell who said that a few experiments performed by the student will give him a more intelligent interest in the subject, and will give him a more lively faith in the exactness and uniformity of Nature, and in the inaccuracy and uncertainty of our observations, than any reading of books, or even witnessing of elaborate experiments performed by professed men of science.

The Tables. — A few heavy flat-topped tables, about thirty-two inches high, four feet wide, and seven feet long, should be provided. These tables should have no iron in their structure; and to make it possible to clamp apparatus on them, the top should project about four inches beyond the frame on each side.

Tools. — In one corner of the room, or preferably in an adjacent room, there should be a carpenter's work-bench, provided with *vice*, *anvil*, *saw*, *plane*, *brace*, *drills*, *hammer*, *chisel*, *soldering-iron*, etc. Such tools will be found useful, and in fact necessary, in constructing simple apparatus, and in making repairs.

Water and Gas. — One or more sinks should be provided, with tables near them, on which to conduct such experiments as may require a continuous supply of water. If there is no water system in the building, a galvanized iron tank might be placed at one end of the sink, and kept filled by a force-pump.

Each table should be supplied with coal-gas by pendants from the ceiling, or brackets on the side-wall, the gas being brought to the table, when needed, by means of rubber tubing. This plan will make it possible to move the tables about the room, changing the arrangement to suit the exigencies of the work. It also frees the tables of obstructions, and introduces no iron pipes beneath them to interfere with magnetic needles.

Reference Books. — It is recommended that a bookcase be provided and well filled with reference books, to which the students may have free access. Such books as the following are recommended: —

"Ganot's Physics," by Atkinson; "Deschanel's Natural Philosophy," by Everett; Daniell's "Physics;" Carhart and Chute's "Elements of Physics;" Cooke's "Chemical Physics;" Lodge's "Mechanics;" Thompson's "Electricity and

Magnetism;" Poyser's "Magnetism and Electricity;" "Heat," by Madan; "Heat," by Tyndall; "Lectures on the Electromagnet," by Thompson; Fleming's "Short Lectures to Electrical Artisans;" "Elementary Practical Physics," by Stewart and Gee; "Practical Physics," by Glazebrook and Shaw; "Physical Manipulations," by Pickering; "Experimental Physics," by Weinhold; "The Art of Projecting," by Dolbear; "Practical Mechanics," by Perry; "Physical Measurements," by Whiting; "Lessons in Physical Measurement," by Earl; "Practical Physics," by Barrett and Brown; "Heat," by Glazebrook; "Light," by Glazebrook; "Sound," by Mayer; "Sound," by Tyndall; "Practical Electricity," by Ayrton; "Handbook of Electrical Testing," by Kempe; "Primary Batteries," by Carhart; "Mechanics, Sound, and Light," by Carhart; "Optical Projection," by Wright; "Lessons and Exercises on Heat," by Hall; "Experimental Science," by Hopkins; "The Nature of Light," by Lommel; "Light," by Wright; "Popular History of Science," by Routledge; "Physical Constants," by Everett; Lupton's "Numerical Tables;" "Electrical Rules and Tables," by Munro and Jamieson; "Arithmetic of Magnetism and Electricity," by Morrow and Reid.

The walls of the room would be more attractive if they were decorated with the pictures of distinguished scientific men. Bare walls are not very inspiring; good work is not wholly independent of the student's surroundings. Charts of spectra neatly framed would be both useful and ornamental.

It is not to be expected, however, that every luxury, or even every convenience, can be provided at the outset. Let the essentials be secured, and then add from time to time such fixtures as will enable the student to do his work with greater accuracy and at less inconvenience.

II. APPARATUS.

How Obtained. — It is a mistake to suppose that elaborate and highly finished apparatus is necessary for successfully prosecuting experimental work. Utility, durability, and efficiency should be considered before display. One should not expect to be able to provide all the required appliances for this manual at the outset. First secure the more important pieces, and then add others as opportunity offers. Much valuable work can be done with a few wisely chosen pieces. A limited amount of apparatus construction by students might be permitted. Nearly every class has its handy boy, whose mechanical gifts can be turned to good account by having him construct some of the simpler apparatus described in connection with the problems. The school janitor is generally a man of some mechanical skill, and can construct frames, supports, and many useful things that will be permanent additions to the collection. Then, if you would succeed, you must turn your own mechanical gifts to account, and spend many an hour at the carpenter's bench or the experimental table, when the other teachers of the school are probably enjoying a rest from labor. The local mechanics of the city or town can build much of the apparatus you may need, and school boards will rarely be found unwilling to spend a few dollars in this way, though they would probably refuse to appropriate a like sum to be spent in some distant city.

The following well-known dealers in and manufacturers of school apparatus can supply any instrument described in these pages: The Franklin Educational Co. of Boston, Mass.; E. S. Ritchie & Sons of Brookline, Mass.; Queen & Co. of Philadelphia, Pa.; and the Eberbach Drug and Chemical Co. of Ann Arbor, Mich. The author, having had dealings with all of these firms, can heartily commend them to the patronage of his fellow science teachers.

Importing Apparatus. — Europe is the great storehouse of physical apparatus; and, under the law, school officials can import school supplies free of duty. In this way a saving of 30 to 50 per cent can often be effected. This is especially true in the matter of balances, weights, barometers, lenses, mirrors, etc. This importing can be done through any of the above mentioned houses.

Cost of an Equipment. — Many schools are deterred from introducing laboratory methods by false notions regarding the cost. Investigation will show that the first outlay need not be large. Experiments requiring expensive pieces may at first be omitted without seriously affecting either the continuity or the efficiency of the work. Nearly every school already possesses such instruments as air-pump, electrical machine, and their numerous accessories. A few dollars spent for scales, calipers, graduates, balances, lenses, and raw material such as glass tubing and insulated copper wire, with a room arranged with tables, would enable many a school to fall into line and impart genuine worth to their teaching of physics.

III. LABORATORY MANAGEMENT

Methods. — There are in use two methods of conducting laboratory work, the *separate system* and the *collective system.* Under the former the students work on different problems, the apparatus going around in rotation. It is difficult, under this plan, to have the student's work conform to a strictly logical order; but, on the other hand, it requires little or no duplication of apparatus. The collective system is the ideal one. Under it all are engaged on the same kind of work at the same time. It has this advantage over the separate system: a teacher can instruct all at once on any point demanding more than ordinary care, and can give more attention to the few who may be less apt in their work. A combination of the two is probably the best plan for most schools, in that it avoids the duplication of expensive pieces of apparatus, and permits it in the case of the less costly.

Sections. — Probably the greatest difficulty experienced in experimental physics is to accommodate the large number of students who desire to take up the subject. The author's plan has been to divide his class into sections of about twenty each, placing two at each table on the same problem. Where classes are so large, it is generally impossible to provide for more than three hours per week; but if these are well spent, the majority, if not all, of the problems in this manual can be satisfactorily studied in a year.

Assignment of Work. — The problems that each student is expected to solve on his appointed day in the laboratory should be assigned to him a few days in advance. An effective and convenient way is to have each section and table numbered; and then, by a notice posted in a suitable place a week in advance, each student can ascertain what problems he is expected to prepare upon. The author has practised this plan for several years, and has found it in every way satisfactory.

Abridgment of Work. — Teachers should feel perfectly free to omit any problem or set of problems that they choose. Although all problems are not equally important, yet circumstances will often determine which are to be omitted. To lessen the expense of introducing laboratory practice, it is recommended to duplicate only the cheaper pieces, and to omit the following problems: 25, 28, 29, 33, 39, 42, 43, 52, 61, 63, 90, 92, 94, 95, 105, 107, 122, 123, 124, 131, 132, 133. Of these, it would be wise to add 25, 29, 39, 63, 90, 123, and 132 to the laboratory list as soon as facilities can be supplied. This principle, however, should govern the work: a few problems thoroughly studied will benefit the student more than many superficially gone over.

The School Programme. — In arranging the school programme, some provision should be made for laboratory practice. Physics should never be placed earlier in the school curriculum than the third year. It would be better still to find a place for it in the fourth. The students then come to that study with some mathematical training, which is absolutely necessary to master modern physics. The daily programme should be so planned that the students in physics will have one-half of a day each week free for their experimental work. To divide up their time in the laboratory into short periods is to waste the larger part of it; for if the time is not sufficiently long to complete an investigation begun, it frequently happens that the part done is lost by having to stop before the whole is completed.

The didactic instruction should run along parallel with the experimental, but a little in advance. At least three recitations per week should be devoted to this work, some suitable text-book being used for the purpose. The objection that is sometimes heard that a student must buy two books is a very shallow one, and may properly be considered as a relic of the Dark Ages. Who ever thinks of objecting to buying three or four books to enable his boy or girl to study a dead language? Dictionaries and grammars are known to be absolutely necessary. So it should be in studying a science. The student should have what is necessary to insure thorough work, and no intelligent person ought to object to purchasing two small books for a year's study in a subject of such great practical and educational value as modern physics.

TO THE STUDENT.

If you would succeed in the study of the problems presented in this manual, observe carefully the following: —

1. Be orderly and neat in manipulation. *Keep all apparatus clean,* never setting away any apparatus without wiping it with a chamois or soft cloth.

2. Economize time by remembering that frequently two operations can be carried on simultaneously; *never,* however, *if either one needs close and constant attention* during any considerable period of time.

3. *Prepare thoroughly beforehand* for every experiment, so that every condition may be faithfully observed, and no failure result from a neglect of some requisite. Do not substitute for what is the best you can provide, that which will barely do.

4. Ascertain the reason for every step taken in working through an experiment, noting which are essential conditions permitting no variations, and which are non-essential only in so far as they conduce to greater accuracy, and hence may be modified as circumstances may suggest or make necessary.

5. *Be exact and methodical.* Let nothing pass unnoticed, although you may not see its significance at the moment. *Use your own eyes.*

6. Keep your note-book by you, and record in it carefully, neatly, and *at the time,* the results of your observations, and also make sketches of the apparatus used. *Tabulate facts whenever possible.*

7. Never enter on a new experiment till you have disposed of the last one in a manner satisfactory to yourself and to the teacher in charge of the work.

CONTENTS.

CHAPTER I.

PAGE
INTRODUCTION 1

CHAPTER II.

SIMPLE MEASUREMENTS, —

I. Measurements of Length, Area, and Volume . . . 8
II. Measurement of Mass 26
III. Cohesion 36

CHAPTER III.

MECHANICS OF SOLIDS, —

I. Composition of Forces 43
II. Curvilinear Motion 46
III. Accelerated Motion 49
IV. The Pendulum 51
V. The Simple Machines 54

CHAPTER IV.

MECHANICS OF FLUIDS, —

I. Pressure in Fluids 60
II. Pressure on the Bottom of a Vessel 63
III. Law of Boyle 65
IV. The Siphon 67
V. The Principle of Archimedes 68
VI. Determination of Density 70

CHAPTER V.

HEAT, —

PAGE
I. The Thermometer 77
II. Conduction of Heat 79
III. Radiation 81
IV. Expansion by Heat 82
V. Melting and Boiling Points 88
VI. Calorimetry 91

CHAPTER VI.

MAGNETISM AND ELECTRICITY, —

I. Magnetism 101
II. Static Electricity 108

III. Current Electricity,—

a. Local Action, Current Direction, Polarization . 111
b. Electrical Measurements 115
c. Action of Currents and Magnets on Currents . . 131
d. Current Induction 134

CHAPTER VII.

SOUND, —

I. Re-enforcement of Sound 137
II. Velocity of Sound 140
III. Reflection of Sound 144
IV. Pitch of Sounds 145
V. Laws of Vibrating Rods and Strings 147
VI. Optical Study of Sounds 151

CHAPTER VIII.

LIGHT, —

I. Images Through Small Apertures 154
II. Photometry 156
III. Reflection of Light 159
IV. Mirrors 162
V. Refraction of Light 171
VI. Lenses 175

APPENDICES.

PAGE
A. — Directions for Making Apparatus 185
B. — Laboratory Operations 193
C. — Physical Constants, —
I. Capillarity 199
II. Densities of Various Substances 199
III. Electrical Resistance 202
IV. Approximate Electromotive Force of Primary Batteries 202
V. Electrical Resistance, etc., of Copper Wire 203
VI. Acceleration due to Gravity 204
VII. Relative Thermal Conductivity 205
VIII. Boiling-points of Substances 205
IX. Coefficients of Expansion 205
X. Latent Heats of Liquefaction and Vaporization . . 206
XI. Melting-points 207
XII. Specific Heat 207
XIII. Indices of Refraction 208
XIV. Mensuration Rules 208
XV. Lengths of Seconds Pendulum 209
XVI. Velocity of Sound at 0° C. 209
XVII. Tenacity 209
XVIII. Trigonometrical Functions 210
XIX. Some Useful Numbers 212
XX. Reduction Rules 213
D. — Price List of Apparatus and Material 214

PHYSICAL LABORATORY MANUAL.

CHAPTER I.

INTRODUCTION.

1. The Note-book. — Each student should have a note-book in which to record the work done by him in the laboratory. It should be known as the **Laboratory Note-book,** and should be devoted *exclusively* to the work of the laboratory. It should be made of good paper, which, for convenience in drawing figures, tabulating facts, and representing related quantities by curves (**6**), should be ruled in small squares. All records of results obtained in any experiment should be made on the right-hand page; the left-hand page facing these results being reserved for diagrams and computations. All notes should be carefully written with due regard to clearness and completeness of statement; all measurements of magnitude should be tabulated. The laboratory hour *should not be devoted to writing discussions of experiments, nor to making computations,* only so far as the results of these computations may be needed for immediate use; on the other hand, it should be given up *wholly to observational work, collecting data to be used and studied at home.* No records should be made and taken from the laboratory on loose leaves of paper, since these are liable to get mislaid. The note-book should always be made the book of original entry, thereby excluding errors due to copying and to defective memory.

All readings of magnitudes should be recorded in the terms given by the scale of the instrument. When reduced to other forms, the reductions should be recorded separately and distinctly marked as such.

Avoid crowding the notes; give the record plenty of room, and aim to make it intelligible to others. Make the record full. It is better that it should contain an occasional irrelevant fact, than that important ones necessary to a full analysis of the problem should be omitted.

2. Preparation. — As thorough a study as possible without actually manipulating the apparatus should be accorded to each problem before undertaking its solution in the laboratory. In this way the time spent in the laboratory can be made much more productive of results; the work done will be intelligently done, more accurately done, and more quickly done, since the student will have only the manipulation to learn, the principles involved being already in mind.

3. The Weekly Report. — On the completion of any experiment, the student should submit his note-book to the instructor in charge of the laboratory for examination and approval, before taking up another experiment. This preliminary report consists of the following parts: (1) *A statement of the object of the problem, followed by the date on which the work was done.* (2) *The apparatus used,* each piece being designated in such a manner that subsequent identification will be possible. (3) *The manner of conducting the experiment,* wherever it differed from the plan outlined in the text-book. (4) *The records made in the laboratory as the experiment proceeded,* the several determinations of the same thing being recorded in tabular form, and all related quantities appearing in parallel columns properly designated.

This preliminary report should be supplemented by the addition of the following, and handed to the instructor at the end of the week: (5) *An account of the theory of the experiment,* presenting any mathematical considerations bearing on the conclusions to be established. For example, if the problem be that of finding the density of a substance, it should be pointed out what is meant by density, and how it is related to the magnitudes it is proposed to measure in the course of the experiment. (6) *References to books consulted in preparing the report,* giving title and page. (7) *Additions to the table of results of the computations* found on the opposite page. (8) *The discussion of the results obtained.* The student should study the observations he has recorded with a view of finding out their interpretation. Whenever possible, he should compare them with those given by theory, and compute the amount of the error. He should carefully examine the method pursued in conducting the experiment, and ascertain all the principal sources of error.

Every part of the report should be written with great care, both from a scientific and from a rhetorical standpoint, since the report will be an accurate measure of the mental acumen of the student.

4. The Term Report. — The student should correct all errors pointed out by the instructor, rewriting the report if necessary, to put every point in proper form. This revised report should be submitted at the end of the term for more careful examination.

5. Errors in Observing. — Errors are unavoidable. Absolute accuracy is impossible. The value determined for any quantity is just as liable to be greater than the true value as it is to be less. The calculated mean of a large number of observations is probably nearer the true value than any single determination. By taking a large number of observations, the student acquires facility in handling the apparatus, becomes more familiar with the principles applied, and thereby is likely to increase the accuracy of his work.

On account of the facility with which errors are made, it is advisable to vary the conditions as much as possible, to the end that new combinations may arise and the repetitions of old errors be avoided. "Check methods" should be used whenever possible; even if not calculated to give close results, they will assist in detecting errors. The aim should be to secure the highest degree of accuracy attainable with the quality of apparatus and the amount of time at one's disposal.

All observations should be recorded, even if known to be far from right, unless they were made simply for practice. If any observations are discarded in the calculations, reasons for doing so should be entered in the notes.

6. Graphic Representation of Data. — This method is employed to show to the eye the relation between two quantities which are so connected that any change in the value of one is attended by a change in the other; as, for instance, the height to which water rises in a capillary tube is greater the smaller the diameter of the tube. It consists in representing by a line the data obtained by the observer in the course of his investigations, the shape of the line indicating the form of the law connecting the interdependent facts.

To construct the line,.procure a piece of cross-section paper of suitable size, or use a page of the note-book if the ruling is accurate, and of the kind specified in Art. 1. The cross-section paper is preferable, since the small squares are of known value, being usually either 1 mm. or .1 inch on a side. Select some suitable scale to be used in representing the things to be compared, the chief condition being that the scale unit should be such as will bring all the work on the sheet or page.

In some instances the sum of the sides of several of the squares may constitute the linear unit; in others, the side of a square may represent several units. It is not necessary that the same unit be chosen for both magnitudes involved. After selecting suitable units, measure toward the right on the horizontal line passing through the corner of some one of the squares, called the **Origin**, a sufficient number of spaces and parts of a space to represent the numerical value of the first of the dependent quantities; and then, in the perpendicular through the point just located, measure off a distance to represent the numerical value of the second quantity, marking the point thus located. In like manner locate points, using the remaining data, making all the measurements from the same origin, and employing the same units. Negative data must be measured off in directions exactly opposite to those used for positive quantities. Through the points located sketch as smooth and symmetrical a curve as possible. The greater the number of points, and the closer they are together, the easier it will be to sketch the curve. The simpler the line passing through these points, the less complex the law connecting the quantities; as, for instance, a straight line would imply that one quantity is proportional to the other, but a curve line would imply that the law connecting the two quantities was more complex. These horizontal measurements are called **Abscissæ**; those at right angles to them, **Ordinates.**

On account of the errors which unavoidably enter into all observations, the points will not all lie exactly on a smooth curve, but may be a little to one side of it. Hence the curve often points out where mistakes have been made by the observer. It is also of service in getting approximate values for the dependent quantities at stages in the phenomena where no observations were taken.

To illustrate the process, suppose two quantities, *A* and *B*, to have the following values: —

A	*B*	*A*	*B*
1	128.00	8	16.00
2	64.00	10	12.80
4	32.00	12	10.66
6	21.33	14	9.14

Lay off on the horizontal line *OX* (Fig. 1), measuring from *O* to the right, the values of *A*; and on verticals through these points the corresponding values of *B*, locating the points *a*, *b*, *c*, *d*, etc. The curve *CD*, through these points, is the one required.

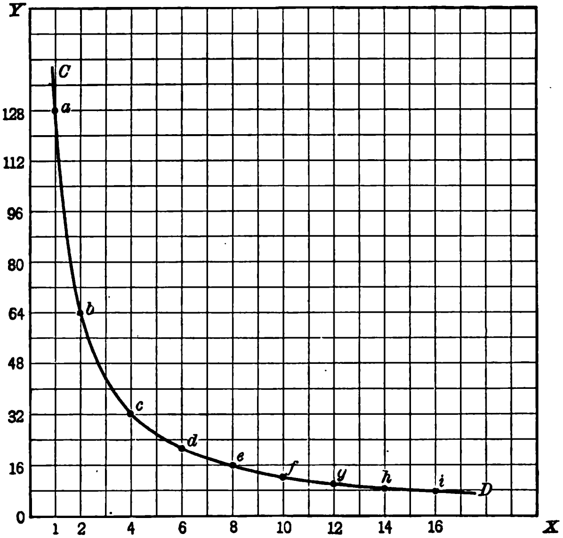

Fig. 1.

CHAPTER II.

SIMPLE MEASUREMENTS.

I. Measurements of Length, Area, and Volume.

7. Measurement in General. — The process of measurement consists in comparing the magnitude, either directly or indirectly, with some assumed standard in order to ascertain the numerical relation between them. The accuracy of the results obtained will depend upon that of the standard, upon the methods adopted to insure close comparisons, and upon the carefulness of the experimenter. A direct method is one in which there is an actual application of the standard unit of measure to the thing to be measured. An indirect method is one in which other quantities than the one stated in the problem are measured, and the values sought are deduced from these data by a mathematical process. A simple illustration of this method is seen in the problem of finding the area of a triangular figure by measuring the length of its sides and computing the area by certain geometrical relations.

8. Units Employed. — In the measurement of **Length** there are two standard units in general use, the **Metre** and the **Yard.**[1] The former is defined as the distance between two lines at 0° centigrade, on a platinum-iridium bar deposited at the Office of Weights and Measures at Washington. The latter may be defined as equal to $\frac{3600}{3937}$ metre. The yard is divided into three equal parts called **Feet**, and each foot into twelve equal parts called **Inches**. The inch is subdivided, either decimally, or into 8, 16, 32, or 64 equal parts. The metre is subdivided decimally into 10 decimetres, 100 centimetres, or 1000 millimetres. In writing quantities in the metric system, the decimal notation should be used; 123 m. 4 dm. 5 cm. 6 mm. should be written 123.456 m.

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[1] The only system of weights and measures that has received the sanction of Congress is the Metric system.

The Units of Area are derived from those of length, and are usually squares whose sides are some one of the units of length, as the **Square Inch** (sq. in.), **Square Foot** (sq. ft.), **Square Millimetre** (smm.), and **Square Centimetre** (scm.), where the sides are 1 in., 1 ft., 1 mm., and 1 cm. respectively.

The Units of Volume are also derived from those of length, and are usually cubes whose edges are some one of the units of length, as the **Cubic Inch** (cu. in.) where the edge is 1 in., the **Litre** (l.) where the edge is 1 dm., the **Cubic Centimetre** (ccm.) where the edge is 1 cm., etc.

9. Relation of the Metric to the English Units. — The value of the metre is 39.37 inches. Hence, if any linear quantity expressed in inches be divided by 39.37 the quotient will be metres; and if any such quantity expressed in metres be multiplied by 39.37 the product will be inches. The inch is equivalent to 2.54 centimetres, or 25.4 millimetres; the square inch to 6.452 scm., the cubic inch to 16.387 ccm. See Table XIX.

10. Problem. — *To measure the distance between two points formed by intersecting lines.*

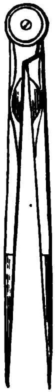

Fig. 2.

Apparatus. — A pair of **Dividers** (Fig. 2) and a **Diagonal Scale** (Fig. 3). The former is merely a pair of compasses with fine steel points. The latter is a scale of equal parts, having eleven equidistant parallel lines running lengthwise of the scale, and divided into a number of equal parts by perpendicular lines. The distance between two consecutive perpendicular lines is the unit of the scale, and is usually $\frac{1}{2}$ in., 1 in., 1 cm., or 2 cm. This unit at one end of the scale, on both the first and the eleventh horizontal line, is subdivided into ten equal parts, and these points of division are joined by diagonal lines. These slanting lines are $\frac{1}{10}$ of the scale unit apart; and each one intersects a horizontal line at a point nearer to or farther from any perpendicular line than the adjacent line by $\frac{1}{100}$ of the scale unit. The diagonal scale, therefore, reads to hundredths of the scale unit.

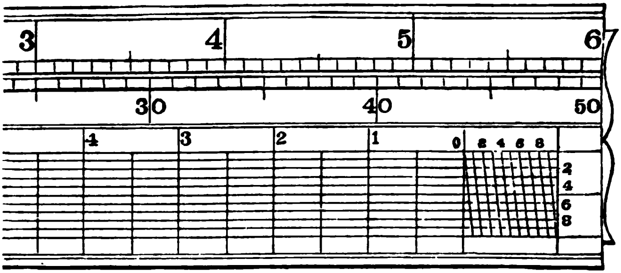

Fig. 3.

Method. — Open the dividers and place one of its points *exactly* on one of the given points, and the other point on the second given point. A pocket magnifier will aid greatly in doing this accurately. Now place one point of the dividers on one of the divisions 1, 2, 3, etc., of the scale, selecting such a one as will cause the other point of the dividers to fall either at 0, or between 0 and the vertical line bounding the scale. If, for example, by placing the left-hand point on the perpendicular 2, the right-hand point falls on 0, then the length is 2 units; but if the right-hand point falls on the diagonal line 3, then the reading is 2.3 units. If, however, the right-hand point falls between 3 and 4, then move the dividers toward the opposite edge of the scale, keeping the line of the points parallel to the horizontal lines of the scale, and at the same time the left-hand point on the perpendicular line 2, until the right-hand point fits exactly on the intersection of a diagonal line with a horizontal one. If this, for example, occurs at the intersection of line 3 with the horizontal line 7, then the reading is 2.37 units. The scale-reading multiplied by the value of the scale unit, expressed either in inches or centimetres, will give the distance sought. After a measurement has been made and recorded, *close the dividers and then repeat the work.* Several independent measurements should be made and their arithmetical mean calculated.

Remarks. — *Avoid pressure,* when the dividers are resting on the scale or on the given points, since the surface might be indented and errors introduced. Hold the dividers at a very oblique angle with the surface. The hinge of the instrument should not work too easily. Hold the dividers so that you are not likely to close them up a little in passing from the given points to the scale. Study every feature of the problem so as to be able to point out the most probable and serious sources of error encountered in solving it.

Form of Record. — The results may be entered in the note-book as follows: —

First Measurement	2.73
Second "	2.71
Third "	2.70
Fourth "	2.71
Mean	2.7125
Value of scale unit, 1 inch.	
Distance between the points	6.89 cm.

11. **Problem.** — *To measure the length and the breadth of table* ...., *employing both the English and the metric measure.* Reduce each to the other, compare them, and point out some of the causes to which are due the differences existing in the results obtained.

Apparatus. — A **Metre-rod**, a needle, and a plane-faced block of wood. The metre-rod, furnished by the American Metric Bureau, Boston, Mass., is a wooden bar, of rectangular cross-section, graduated to millimetres on one face, and to eighths of an inch on the other.

Method. — Apply the scale directly to the object to be measured. The face of the wooden block, as it is held firmly against the edge of the table, will indicate the point at which the measurement should begin. The point at which it terminates may be similarly found. Use the needle to mark any intermediate points that may be necessary.

Remarks.—*Place the edge of the scale on the table*, then the apparent position of any scale division will not be affected by changing the position of the eye, since the divisions on the scale will be in contact with the table. If the end of the scale is not perfect, then use the scale as if its divisions began at 10, correcting each reading by that amount. The scale should be placed *parallel* to the edge of the table. The nearest millimetre, or the nearest eighth of an inch, should not be regarded as near enough. The smallest scale division should be considered as divided into ten equal parts, and any small excess should be estimated by the eye in tenths of this least scale division. Since the English side of the metre-rod has a fractional part, .37 in., it is better when using that side not to use the whole rod in measuring any magnitude longer than the rod.

Form of Record. — The results may be tabulated in the note-book as follows: —

	LENGTH.		BREADTH.	
First Measurement	212.90 cm.	83.75 in.	74.35 cm.	29.254 in.
Second "	212.85 cm.	83.801 in.	74.40 cm.	29.255 in.
Third "	212.90 cm.	83.755 in.	74.36 cm.	29.253 in.
Mean . .	212.88 cm.	83.768 in.	74.37 cm.	29.254 in.
Reduced .	212.77 cm.	83.811 in.	74.31 cm.	29.279 in.
Difference .	.11 cm.	.043 in.	.06 cm.	.025 in.

12. Problem.— *To find the ratio of the circumference of a circle to its diameter.*

Apparatus. —A pair of dividers, a linear scale, two metre-rods, a sharp knife-blade, and cardboard.

Method. — Fasten the knife-blade to one leg of the dividers in such a manner that, in describing a circle on cardboard, the point of the knife will cut out a circular disk. Draw several diameters of the circle and measure them (**10**). Make a mark on the circumference, hold the disk vertically, with the mark *exactly* on a known division of the metre-rod, and roll it along on the rod till the mark is again in contact with it. The difference between the two positions of this mark will be the circumference. In order to roll the disk along a straight line, the second metre-rod should be used as a guide.

Remarks. — Do not permit the disk to slip as it rolls along the scale. Compute the ratio to four decimal places.

Form of Record. — Tabulate results as follows: —

	CIRCUMFERENCE.	DIAMETER.
First Measurement	....	....
Second "	....	....
etc.	etc.	etc.
Mean	....	....

Computed ratio .... True ratio 3.1416

Amount of error .... Per cent of error ....

13. Problem. — *To find the volume of the metal in a piece of brass tubing.*

Apparatus. — The **Verniered Steel Caliper.** Figs. 4 and 5 illustrate two of its common forms: the first where the movable scale or vernier is provided with a slow-motion screw, and the second where it is omitted. The vernier is usually constructed so that *n* of its divisions equal *n* — 1 divisions of the limb or bar. In that case, each vernier division is $\frac{1}{n}$ of a limb division shorter than each limb division.[1] If each limb division is $\frac{1}{50}$ of an inch, and 19 limb divisions equal 20 vernier divisions, then each vernier division is $\frac{1}{20}$ of a limb division shorter than each limb division, or $\frac{1}{20}$ of $\frac{1}{50} = \frac{1}{1000}$ of an inch. What will be the reading of each vernier division, if each limb division is $\frac{1}{10}$ of an inch, and 10 vernier divisions equal 9 on the limb? What will be the reading if each limb division is $\frac{1}{2}$ mm., and 25 vernier divisions equal 24 limb divisions? What will be the reading if each limb division is 1 mm., and 10 vernier divisions equal 9 limb divisions?

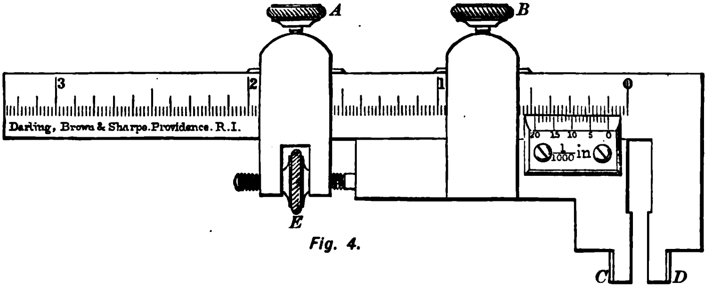

Fig. 4.

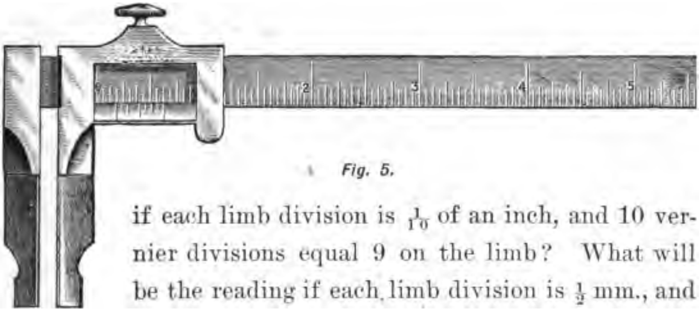

Fig. 5.

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[1] If l is the length of each limb division, and v that of each vernier division, then $n\,v = (n-1)\,l$, $v = \frac{n-1}{n}\,l$, and $l - v = l - \frac{n-1}{n}\,l = \frac{1}{n}\,l$.

Method. — Unclamp the screws *A* and *B*, and slide the jaw *C* away from *D* far enough to admit the cylinder between *C* and *D*, with its axis *parallel* to the limb of the caliper. Then clamp *A*, and move the jaw *C* by the slow-motion screw *E*, till the tube is *just held* between the jaws *C* and *D*. If there is no slow-motion screw, it will suffice to slide the movable jaw *B* along the limb till contact is secured.

To read the instrument, write down decimally the number of limb divisions up to the zero line of the vernier scale; then if the zero of the vernier scale does not register exactly with a division on the limb, observe which one of the vernier divisions coincides most nearly with a division on the limb, and this gives the value of the small space between the zero of the vernier and the limb division that is nearest to it on the side toward the object. For example, if the instrument is graduated like Fig. 4, and if the reading on the limb is 1 inch, $\frac{3}{10}$ of an inch, and $\frac{4}{50}$ of an inch, we would write 1.38 inches; if the zero line of the vernier does not coincide with the line 4, which we have read as $\frac{4}{50}$ of an inch, but is between 4 and 5, then we look along the vernier till the line that coincides most nearly with one on the limb is found. If this line is marked 6, then .006 must be added to the reading already taken, making the completed reading 1.386 inches. It must be borne in mind that the unit of this 6 is determined by the value of the vernier readings as already shown.

The outside diameter is measured in the same way as the length. To obtain the inside diameter, insert the rounded ends of the jaws within the cylinder, adjust, and read as already directed. This reading must be increased by the width of the jaws. If this is not known, it can be found by the aid of a second instrument or by means of the micrometer caliper (**14**).

The volume required is the difference between the volumes of two cylinders, whose diameters are the outside and the inside diameters respectively of the tube. The volume of a cylinder can be computed by the formula $\pi R^2 H$, in which $\pi = 3.1416$, R = radius, and H = length.

Remarks. — The object must not be clamped too tightly, since it may spring the frame of the instrument, and make the readings incorrect. The slow-motion screw should be used very cautiously, stopping as soon as the increased resistance indicates that contact is secured. The screws *A* and *B* should be loosened *just enough* to permit the jaws to slide along; this will prevent the jaw *C* from springing away from the limb.

Form of Record. — The results may be tabulated as follows: —

	LENGTH.	OUTSIDE DIAMETER.	INSIDE DIAMETER.
First Measurement	1.386 in.	.624 in.	.411 in.
Second "	1.385 in.	.625 in.	.412 in.
Third "	1.387 in.	.624 in.	.410 in.
Mean	1.386 in.	.624 in.	.411 in.

Volume of brass = .24 cu. in.

14. Problem. — *To measure the diameter of a wire.*

Apparatus. — The **Micrometer Caliper** (Fig. 6). This instrument consists of a stout, curved steel frame carrying two screws, *B* and *C*, the latter of which moves freely by means of the head *D*. The pitch of the screw *C* can be obtained by observing the value of the space on the linear scale *a*. The circular scale on *D* usually consists of 25 parts when the pitch of the screw is $\frac{1}{40}$ of an inch, 20 parts when $\frac{1}{50}$ of an inch, and 100 parts[1] when 1 mm. Hence, one circular division represents $\frac{1}{25} \times \frac{1}{40} = .001$ in., $\frac{1}{20} \times \frac{1}{50} = .001$ in., or $\frac{1}{100} \times 1 = .01$ mm. On most instruments these circular divisions are sufficiently large to make it possible to estimate to quarters of these spaces.

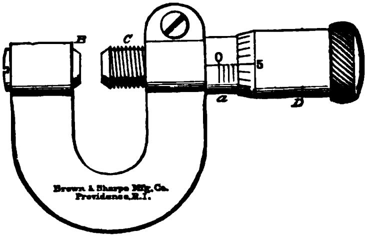

Fig. 6.

When the screw *C* is in contact with *B*, the zero of the scale on *D* should be at the zero of the linear scale *a*. If this is not the case, the set-screw which holds *B* should be loosened, and *B* should be moved till the two zeroes coincide.

Method. — Place the wire to be measured between *B* and *C*, and turn *D* till the wire is held between *B* and *C*. To get the diameter, observe how many spaces on the linear scale *a* are exposed, and what division of the circular scale on *D* coincides with the line running lengthwise of the cylinder having the linear scale.

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[1] Some instruments have a screw ½ mm. pitch, divide the head into 50 parts, and on the linear scale read to millimetres. Two turns of the head will be necessary to move the screw 1 mm. Hence, the head readings are hundredths of a millimetre.

The figure illustrates the following reading: —

On the linear scale (limb), 4 divisions ($\frac{1}{50}$ in.) = .08 in.
On the circular scale (head), 5 divisions ($\frac{1}{1000}$ in.) = .005 in.
Total reading = .085 in.

Remarks. — In clamping the wire between *B* and *C*, it is evident that undue pressure will either spring the instrument or flatten the wire, thereby making the reading incorrect. In turning the head *D*, the operator should stop as soon as he detects that contact has ensued. Some instruments are constructed in a manner to have the milled head on *D* slip around as soon as contact takes place.

Form of Record. — Tabulate the results as follows: —

	Wire No. 8.		Wire No.		Wire No.......	
First Trial.						
Limb Reading	3		....		....	
Head "	.245	3.245 mm.	....	......	....	......
Second Trial.						
Limb Reading	3		....		....	
Head "	.244	3.244 mm.	....	.....	....	......
Third Trial.						
Limb Reading	3					
Head "	.25	3.25 mm.	....	......	....	......
Mean		3.246 mm.		.....		.....

15. Problem. — *To measure the diameter of a ball.*

Apparatus. — Two square-cut blocks, a metre-rod, and **Outside Calipers** (Fig. 7). The angles of the blocks must be square, and their thickness must not be less than the semi-diameter of the ball. The outside calipers are a kind of compass with curved legs. The distance between the inner faces of the points can be adjusted by means of a screw and nut. In the cheaper forms of calipers the adjusting screw is omitted.

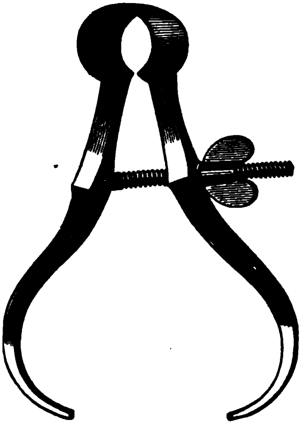

Fig. 7.

First Method. — Press the blocks firmly against the edge of a metre-rod. Between the inner faces of the blocks place the ball. With the blocks touching the ball, read on the scale the distance between them. This will be the diameter sought. Why must the blocks have square corners, and be thicker than the semi-diameter of the ball?

Second Method. — Adjust the distance between the points of the outside calipers so that the ball at its thickest part *just passes between them.* Apply the calipers to a linear scale, like a pair of dividers, to ascertain the distance between the inner faces of the points.

Remarks. — The ball should be measured in different positions.

Form of Record. — The student should devise a suitable form for tabulating the different measurements made by each method.

16. Problem. — *To measure the depth and the diameter of a cylindrical jar, compute its volume, and compare the volume with that obtained by the use of a graduated measure.* Make all the measurements in both systems.

Apparatus. — A metre-rod, a **Graduate** (Fig. 8), and **Inside Calipers** (Fig. 9). The graduate is a glass vessel of cylindrical or conical form, showing on opposite sides the volume in ounces and cubic centimetres. The inside calipers are merely compasses. Outside calipers having no adjusting screw may be converted into inside calipers by sliding the points by each other till the inner faces of the points become the outer ones.

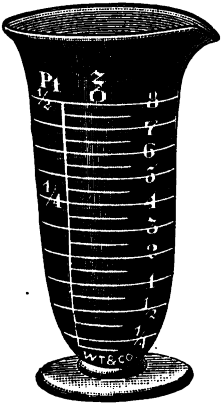

Fig. 8.

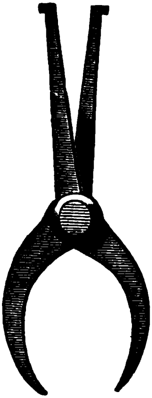

Fig. 9.

Method. — Find the depth of the jar by standing the metre-rod vertically within it, and taking the reading on it at the point opposite the lower surface of a straight-edge resting across the top of the jar. Find the inside diameter by opening the inside calipers within the jar as far as possible, keeping the line of the points *normal* to the sides of the jar, and applying the points to a linear scale to ascertain the distance between the outer faces. Compute the volume[1] by the formula $V = \pi R^2 H$, in which $\pi = 3.1416$, R = radius, and H = depth. To measure the volume, ascertain by means of the graduate how much water it takes to fill the jar.

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[1] To obtain the volume in ounces, compute the volume in cubic inches and multiply by .5541.

Remarks. — The depth should be measured at several places, since the bottom of the jar may not be level. The diameter should be taken at different places, since the jar may not be a true cylinder. The jar is to be considered as full of water when the surface of the water is tangent to the lower surface of a straight-edge placed across the top of the jar. The graduate must rest on a horizontal surface, and the eye must be on a level with the surface of the water when taking the reading. How would the reading be affected by having the line of sight at an angle with the surface of the water? Why does the computed volume differ from the measured one?

Form of Record. — The results may be tabulated as follows: —

	DEPTH.		DIAMETER.		VOLUME.	
First Meas't	.....cm.	.....in.	.....cm.	.....in.	.....ccm.	.....oz.
Second "	.....cm.	.....in.	.....cm.	.....in.	.....ccm.	.....oz.
	etc.		etc.		etc.	
Mean	.....cm.	.....in.	.....cm.	.....in.	.....ccm.	.....oz.
			Computed volume,		.....ccm.	.....oz.

17. Problem. — *To measure the angle formed by two intersecting straight lines.*

Apparatus. — The **Circular Protractor**. This instrument is a brass, German-silver, or translucent horn circle or semicircle, having its circular edge divided into degrees or half-degrees. It is sometimes provided with an arm (Fig. 10) turning about the centre of the circle, and arranged in a manner to keep one of its edges a radius of the circle.

Method. — Place the protractor on the angle, with its centre *exactly* over the vertex of the angle, and the diameter of the protractor (the line joining the zeroes of the scale) on one side of the angle. Then the point where the other side of the angle crosses the circular scale will mark the size of the angle.

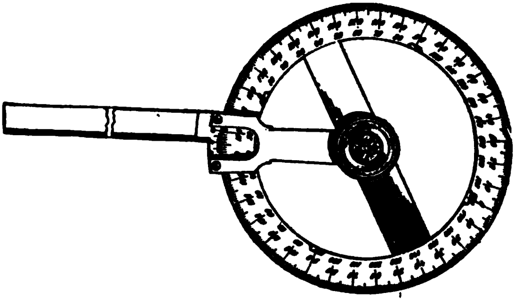

Fig. 70.

Remarks. — In reading the protractor, and in placing it in position, the line of sight must be normal to the plane of the instrument. Why?

Form of Record. — The student should devise a plan of tabulating the results.

18. Problem. — *To find the area of a triangle formed by lines drawn on a page of the note-book.*

Apparatus. — A pair of dividers, a linear scale, and a piece of cross-section paper.

First Method. — Find the length of each side of the triangle by proceeding as in ART. **10**. Compute the area by the formula $A = \sqrt{p(p-a)(p-b)(p-c)}$, in which p is the semi-perimeter of the triangle, and a, b, and c are the sides.

Second Method. — Transfer the triangle to cross-section paper, and find the number of small squares included within its sides. The values of the fractional squares situated along the sides of the triangle must be estimated in tenths.

The triangle may be transferred to the cross-section paper with a fair degree of accuracy, by placing the paper beneath the triangle, puncturing the vertices of the triangle with a fine needle, and joining the marks thus made on the cross-section paper with fine lines.

Form of Record. — The results may be tabulated as follows : —

	SIDE a.	SIDE b.	SIDE c.
First Measurement	....	....	....
Second "	....	....	....
etc.	etc.	etc.	etc.
Mean	....	....	....
Computed area	....	Area by cross-section paper	....

19. Problem. — *To find the volume of a small irregular body.*

Apparatus. — A **Cylindrical Graduate** (Fig. 11), an **Erdmann's Float** (Fig. 12), and a liquid in which the solid is not soluble. The graduate is made of glass, and usually graduated to cubic centimetres. The float is a short, hollow glass cylinder, closed at both ends, and weighted with mercury to make it keep an upright position when floating. A line is etched around it about midway between the ends, to serve as an index.

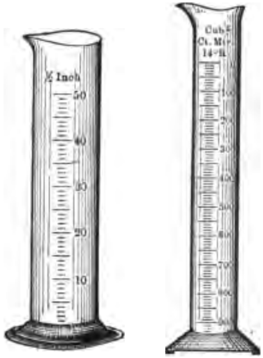

Fig. 11.

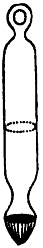

Fig. 12.

Method. — Partly fill the graduate with a suitable liquid, usually water, introduce the float by means of a wire hook, and record the reading on the graduate scale that is exactly opposite the line on the float. Now remove the float and introduce the object to be measured; then reintroduce the float, and obtain the reading as before. The difference between the two readings is the volume of the object.

Remarks. — In repeating the work use different quantities of liquid, in order to bring the readings at different places on the scale. Dry the object each time. In taking a reading, the line of sight should be a diameter of the circular line around the float. Why? All fractions of cubic centimetres must be carefully estimated. When the float is lifted out of the graduate in order to introduce the object, some liquid adheres to it, thereby lessening the amount in the graduate. This error may be avoided by placing the float after removal in a vessel filled with the liquid, since the probability is that the float will carry as much liquid into the graduate on being returned as it carried out.

Such substances as rock-candy, rock-salt, saltpetre, etc., are soluble in water. Hence, the volume of a piece of one of these substances cannot be accurately found by the displacement of water. Alcohol could be used for rock-candy and saltpetre, and sulphuric ether for rock-salt.

Bodies lighter than water must be weighted down by a piece of lead or iron of known volume, and the combined volumes obtained.

Remove all adhering air-bubbles by knocking them off with a wire. Why necessary? Porous substances should have their pores closed with a thin coating of varnish or paraffine. Why is this necessary? Write as a theory for this problem a statement of the physical principles applied in its solution.

Form of Record. — The data obtained may be recorded as follows: —

	FIRST FLOAT-READING.	SECOND FLOAT-READING.	VOLUME.
First observation	83 ccm.	88.25 ccm.	5.25 ccm.
Second "	63 ccm.	68.125 ccm.	5.125 ccm.
Third "	62 ccm.	67.25 ccm.	5.25 ccm.
		Mean	5.208 ccm.

II. Measurement of Mass.

20. Measuring the Mass of a body consists in finding the ratio of the quantity of matter in it to that in some body taken as a standard. The process is called **Weighing**, and the result is commonly spoken of as the **Weight**. The unit of mass adopted in this country and in England is the quantity of matter in the **Avoirdupois Pound**. It is equivalent to 7000 grains. Its chief multiples and submultiples are tons, ounces, and drams. In the Metric System the **Gramme** is the unit. For the purposes of this book it may be considered with sufficient accuracy as the mass of a cubic centimetre of ice-water. It is equivalent to 15.432 grains. It is multiplied and divided decimally; the kilogramme (1000 grammes), the decigramme (.1g.), the centigramme (.01g.), and the milligramme (.001g.) are the denominations most frequently met with in practice.

21. Relation of the Gramme to the Pound.—Pounds are reduced to grammes by multiplying by 453.593, ounces to grammes by multiplying by 28.35, and grammes to pounds and ounces by the converse process.

22. Problem. — *To find the mass of a body.*

Apparatus. — A **Beam Balance** (Fig. 13), and a **Box of Weights** (Fig. 14). The balance consists of a metal beam supported on a V-shaped axis, about which it is free to vibrate in a vertical plane. Pans of horn or metal are attached by cords or metal bails to the ends of the beam. A long pointer is fastened to the centre of the beam, and moves in front of a graduated arc

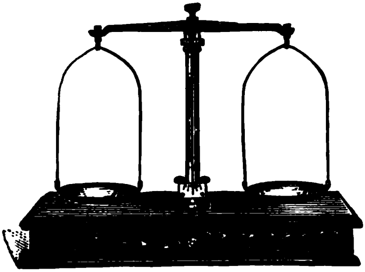

Fig. 13.

Fig. 14.

as the beam vibrates. In the better class of balances the beam does not rest on the bearings when not in use, but is set in action either by depressing a lever, or by turning a milled-head screw conveniently placed on the base of the instrument. Fine balances are protected from dust and air-currents by a glass case (Fig. 15). The weights smaller than a gramme are made either of aluminium or of platinum ; the others are made of brass. Each weight has its value stamped upon it, and has its special place in the box. A small pair of pincers is provided for handling the weights. The fingers should not be used for the purpose.

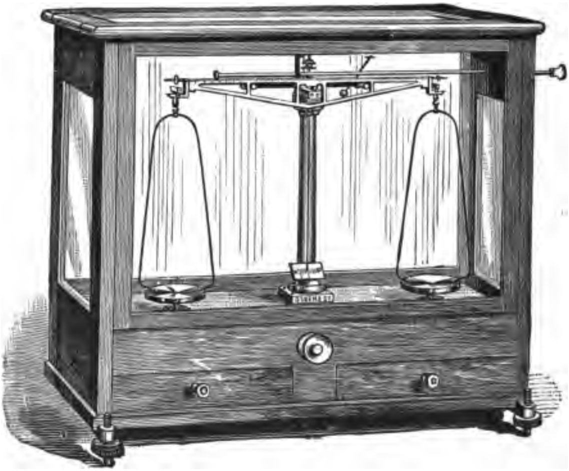

Fig. 15.

First Method. — Place the article to be weighed on the left-hand scale-pan, and as near the middle as practicable. In the other pan place a weight such as you estimate will balance it. Now set the balance in action, and watch the pointer to determine which pan is the heavier; since, if the equilibrium is not close, the pointer will move sharply to one side of the middle of the ivory scale. If the weight is found too heavy, remove it, and substitute a smaller one; if too small, a heavier one. For example, suppose that a 20-gramme weight is found too heavy, it should be replaced by the 10-gramme weight. If this is found too light, then add the 5-gramme weight; if still too light, add the 2-gramme weight; if now too heavy, replace the 2-gramme weight by the 1-gramme; if now too light, add .5-gramme weight; if still too light, add .2-gramme weight; if now too heavy, replace the .2-gramme by the .1-gramme, and so on till the pointer swings equal distances each side of the middle of the ivory scale. It now remains to count the weights. This should be done, first, by counting the weights absent from the box, and, secondly, by counting those on the pan as you remove them from the pan to replace them in the box.

Second Method. — Unless the balance has been carefully adjusted to position, the pointer, when at rest, will generally not coincide with the middle division of the ivory scale. It will therefore be necessary to determine the position of the pointer on the scale when the beam is horizontal. To wait for the beam to come to rest in order to find this resting-point will consume too much time. It can be more quickly done by observations made on the vibrations of the pointer. On account of friction and resistance of the air, this point is not the middle-point of the arc described by the pointer, but is nearer the end of the arc toward which the pointer moves in making its second vibration. It can, however, be found with sufficient accuracy by observing five turning-points of the pointer, and averaging them in the manner shown below. Let us suppose that the ivory scale is divided into 20 parts. Number these divisions from 0 to 20, beginning at the left-hand end. Now observe five turning-points of the vibrating pointer, three to the left and two to the right, or *vice versâ*. These observations should be recorded as follows: —

	TURNING-POINTS.		RESTING-POINT.
	Left.	*Right.*	
	2.5	17	$\frac{16.62 + 3.08}{2} = 9.8.$
	3	16.25	
	3.75		
Mean,	3.08	16.62	

The mean of the three vibrations to the left in the case assumed is 3.08, and of the two to the right is 16.62. The average of these two results, 9.8, is the probable resting-place of the pointer. As soon as the resting-point is secured, then proceed to weigh the article as directed in the first method. When the pointer swings approximately equal distances each side of the middle of the scale, record five of its turning-points, and compute the resting-point as before. Let us suppose that the result is 7.2. Then it appears that there are too many weights in the right-hand pan, since the resting-point is to the left of the true one.[1] To determine the amount to be subtracted, place a small weight, as .001g., on the pan, set the balance in action, and determine as before the resting-point. To illustrate, let us assume that the result obtained is 6.4. Then it follows that .001g. moved the pointer from 7.2 to 6.4, or .8 division. To secure an exact balance it is necessary, however, to move the pointer from 7.2 to 9.8, or 2.6 divisions. Therefore, the amount required will be given by the proportion,

---

[1] This applies to a balance having the ivory scale below the beam; where this scale is above the beam the opposite is indicated.

$$.8 : 2.6 :: .001 : x = .00325 \text{ g.}$$

This amount, deducted from the weight on the pan, not counting the mg. weight last added, will be the weight sought.

Remarks. — The first method is adapted to balances not very sensitive and not enclosed in cases. The second method is to be used with fine balances enclosed in cases to shield them from air-currents.

The following summary of directions must be carefully observed if accurate results are expected: —

1. Remove all dust from the pans by means of a camel-hair brush.

2. The position of the observer must be central, so that the line of sight will be normal to the ivory scale.

3. If the balance fails to vibrate on turning the mill-head, throw air against one of the pans by a downward motion of the open hand.

4. In arresting the balance, always wait till the pointer is over the centre of the scale. To do otherwise will jar the instrument, and possibly injure the bearings.

5. *Always arrest the balance before adding or removing* weights. If there is no provision for the purpose, steady the pan with the hand.

6. Avoid air-currents and jarring the supporting table, as these will cause the balance beam to vibrate irregularly.

7. *Keep the weights in the box* when they are not in use on the scale-pan. *Ascertain the number of weights in the box before beginning to weigh,* and be sure that each weight is in its place when the operation of weighing is completed.

8. Never place anything on a scale-pan that is hot, wet, or likely to mar it. Always protect the pan in some suitable way.

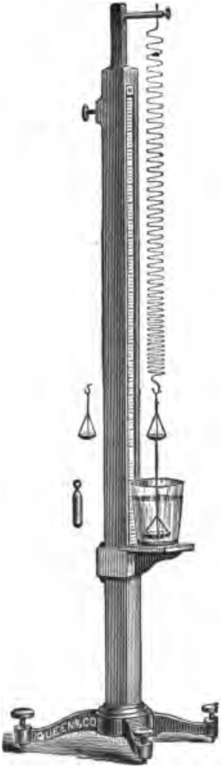

Fig. 16.

23. Problem. — *To find the weight of a body by means of Jolly's balance.*

Apparatus. — **Jolly's Balance** (Fig. 16), and a set of weights. The illustration shows the balance in one of its most complete forms. In App. A. , directions are given for constructing a modified form that will be found quite efficient. The plan of the instrument is to have a delicate spiral spring suspended in front of a glass mirror-scale. A scale-pan for holding the body to be weighed is attached to the lower end of the spring, and a small bead just above the pan serves as an index. The scale-reading is where the line joining the index with its reflection intersects the scale.

Method. — Place the body in the pan and record the reading of the index. Now remove the body, and add weights till the same reading is obtained. The sum of the weights is the weight of the body. If it is found impossible to bring the index exactly to the same reading as it had when the body was in the pan, add weights till a reading less than the required one is obtained, but such that the smallest weight in the box, when added, brings the index too low. If, for example, the reading required is 300, and .01 gramme changes it from 299 to 301.5, then the true weight will be the weights in the pan, exclusive of .01 gramme, increased by $\frac{1}{301.5-299}$, or $\frac{1}{2.5}$ of .01 g. = .004 g.

24. Problem. — *To measure the diameter of a small tube, not capillary, but too small to permit the use of the verniered caliper.*

Apparatus. — Micrometer caliper (**14**), balance, linear scale, mercury, dropper-bulb, and rubber tubing.

First Method. — Accurately fit to one end of the tube a stopper or plug of soft pine. If the wooden plug be crowded gently into the tube, and at the same time turned on its axis, it will conform to the opening, and give its size with a fair degree of accuracy. The diameter of this stopper can be obtained by the micrometer caliper (**41**), and will be very nearly that of the tube.

Second Method. — Thoroughly clean the tube by washing it, first in hydrochloric acid, secondly in distilled water, and lastly in alcohol. To do this, attach a small dropper-bulb to a glass tube, connect this glass tube to the tube to be cleaned by a piece of rubber tubing; then place one end of the tube in a short bottle containing the cleaning liquid, and alternately compress and relax the bulb. This will make the liquid pass to and fro through the tube and remove the adhering matter. Dry the tube by passing a stream of hot air through it, or by holding it in the heated gases rising above a Bunsen flame. After cleaning the tube, close one end of it with a square-faced plug of wax, hold the tube in a vertical position, and, by means of a dropper (such as is used in filling fountain pens), pour in enough mercury to fill it to a depth of about 5 cm. Find the *exact* length of this mercury column (**10**); then pour the mercury into a small glass of *known weight* and find its weight. Since a cubic centimetre of mercury weighs 13.6 grammes, then the weight of the mercury in grammes, divided by 13.6, will give the volume of the mercury cylinder in cubic centimetres. This volume, divided by the length of the cylinder, will be the area of the cross-section. Divide this cross-section by .7854, and extract the square root of the quotient to ascertain the diameter of the cylinder or tube.

Remarks. — The length of the mercury cylinder should be taken to the lower edge of the curved surface. This length is too small, on account of the depression of the mercury next to the walls of the tube, but is nearly offset by the fact that the mercury does not fill the tube on account of a thin film of air between it and the walls of the tube.

Form of Record. — The data obtained may be entered in the note-k as follows: —

THE EMPTY GLASS VESSEL.

UNLOADED BALANCE.		LOADED BALANCE.		.001 g. ADDED TO PAN.	
2	17.5	2.5	18	2.5	16.5
2.5	17	3	17.5	3	16
3		3.5		3.5	
Resting-point = 9.87		Resting-point = 10.38		Resting-point = 9.62	

Weights on pan, $10 + 5 + 2 + 1 + .05 + .01 + .005 = 18.065$ g.
Correction to be added, $.76 : .51 :: .001 : x = .0007$ g.
Correct weight of vessel, $18.065 + .0007 = 18.0657$ g.
Length of mercury cylinder $(5.12 + 5.13 + 5.11) \div 3 = 5.12$ cm.

VESSEL AND MERCURY.

	1.2	18.1	1.8	18
Resting-point = 9.87	2	17	2.5	17
	2.5		3	
	Resting-point = 9.72		Resting-point = 9.9	

Weights on pan, $20 + 10 + 10 + 2 + 1 + .5 + .02 + .01 = 43.52$ g.
Correction to be subtracted, $.18 : .15 :: .001 : x = .00083$ g.
Weight of vessel and mercury $= 43.52 - .0008 = 43.5192$ g.
Weight of mercury $= 43.5192 - 18.0657 = 25.4535$ g.
Volume of mercury $= 25.4535 \div 13.6 = 1.871$ ccm.
Area of cross-section $= 1.871 \div 5.12 = .3654$ scm.
Diameter of tube $= \sqrt{.3654 \div .7854} = .682$ cm.

25. Problem. — *To measure the diameter of a capillary tube.*

Apparatus. — Same as in ART. **24.**

Method. — Proceed as in the second method of ART. **24.** It will not be necessary to close one end of the tube. Partially fill the tube with mercury by submerging it in a dish of mercury. While submerged, close the ends with the thumb and first finger; then lift the tube out, brush off all clinging globules of mercury, tip the tube till the mercury filament moves to the middle portion of the tube, and then lay it down on a level surface while measuring the length of the filament.

Form of Record. — Same as in Art. 24.

III. Cohesion.

26. Problem. — *To measure the tenacity of a wire.*

Apparatus. — A **Draw-scale** or **Spring Balance** (Fig. 17), of 50 lbs. capacity, a wire micrometer (Fig. 6), two wooden rods, each about 30 cm. long and 2.5 cm. in diameter, and provided with a stout wire bail. The rods may be pieces of a broom-handle. A hole about 1 mm. in diameter should be bored through the middle of each rod.

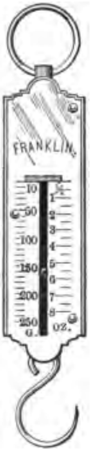

Fig. 17.

Method. — Pass the end of the wire to be tested through the hole in one of the rods, and wind it several times around the rod, passing the end a second time through the hole to prevent slipping. Fasten the other end of the wire to the other rod in a similar manner. Attach one of the wire bails to a hook in the wall, and the other to the hook of the draw-scale. Now measure the diameter of the wire in several places with the wire micrometer (**14**), and then pull on the ring or frame of the draw-scale till the wire breaks, recording the reading of the scale-index at the moment of rupture. Repeat several times, measuring the diameter both before and after breaking.

The breaking-weight divided by the area of the cross-section of the wire expressed in square millimetres is the measure of its tenacity. The area of the cross-section equals $.7854\,d^2$, in which d is the diameter of the wire.

Remarks. — Only small wires can be broken in this way. Wires larger than No. 24 may be easily broken by means of a lever. The force applied to the long arm can be measured by the draw-scale, and the stress on the wire computed by multiplying the reading of the scale by the ratio of the arms of the lever.

Avoid kinks in the wire. Keep the eye fixed on the index, so as to notice its position at the moment of breaking. The line of sight must be normal to the face of the balance.

Form of Record. — Enter the results as follows: —

KIND OF WIRE.	DIAMETER.	CROSS-SECTION.	BREAKING-STRAIN.	TENACITY.
Iron	0.575 mm.	0.25965 smm.	25.5 lbs.	98.20 lbs.
Iron	0.286 mm.	0.06424 smm.	7.16 lbs.	111.45 lbs.
Steel	0.548 mm.	0.23585 smm.	42.66 lbs.	180.87 lbs.

27. Problem. — *To ascertain how the size of a drop of a liquid is affected by the cohesion of the liquid, the shape of the surface on which the drop forms, and the rate of drop-forming.*

Apparatus. — A balance, two or three glass bulbs or round-bottomed flasks of different sizes, a **Funnel** (Fig. 18) with a short piece of rubber tubing attached to its stem, an adjustable **Pinch-cock** (Fig. 19), an **Iron stand** (Fig. 38), and a **Retort stand.**

gravity balance with one scale-pan supported by a short bail, a box of clean dry sand, and a few ounces of mercury. The disks should be supported by three cords attached at points 120° apart (Fig. 20).

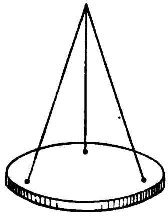

Fig. 20.

Method. — Clean the surface of the disk *thoroughly,* suspend it beneath one of the scale-pans, and find its weight. Now place either the vessel of water or mercury beneath the disk, and adjust its height so that the disk just touches the surface of the liquid when the balance-beam is horizontal. *The surface of the disk must be horizontal.* Pour sand slowly into the opposite pan till the disk is broken loose. Weigh the sand and deduct from it the weight of the disk. The difference will be the separating force.

Remarks. — In bringing the disk in contact with the liquid, first touch one edge, and then gradually shut down the disk upon the liquid, thereby excluding air-bubbles. Avoid getting the liquid on top of the disk. The copper disk must be amalgamated[1] with mercury before bringing it in contact with the mercury in the dish. The surface of the disk must be free from oil. The fingers must not be rubbed over it.

Form of Record. — Tabulate the results as follows: —

Disk.	Weight.	Wt. of Sand Used.	Separating Force.	Average Force.
....	....	....	....	
		....	....	
		....	....	....

---

[1] To amalgamate the copper disk, first clean it with dilute sulphuric acid, and then rub it with mercury.

Queries. — Answer in the discussion the following: Was the disk pulled away from the liquid in each case? How does the force required to separate copper from mercury compare with that required to separate glass from mercury?

29. Problem. — *To test the laws of capillary action.*

Apparatus. — An accurate balance, mercury, linear scale, and several capillary tubes differing in diameter.

Method. — Clean the tubes and measure their diameters as directed in ART. **25**. Cut a strip of zinc about 10 cm. long and 1.5 cm. wide. Trim one end to a V-form, tapering it back about 1 cm. Coat the strip with a thin film of paraffine. Cut in the paraffine two lines parallel to the edges of the strip, about .5 cm. apart, and with the point of the strip about midway between them. Tie a capillary tube on each line, each tube projecting about a centimetre beyond the V-point. Support the strip as accurately as possible in a *vertical* position, with the point of the V *just touching* the surface of the water in a vessel. Now lift up the vessel containing the water so as to wet the capillary tube some little distance above that to which the liquid will rise by capillary action, and then lower it to its original position. After waiting a minute for the water to fall to its proper level, mark in the paraffine with a fine needle the position of the *bottom of the curved surface* of the water within the tube. The distance of this mark from the point of the V, increased by one-sixth of the diameter to correct for the meniscus, will be the height of the water due to capillarity. Multiply the corrected height by the diameter of the corresponding tube. These products, if the work has been accurately done, will be nearly equal, showing that the height varies inversely as the diameter of the tube.

Using one of the tubes, determine the height to which other liquids rise, as alcohol, benzine, turpentine, etc. Also try water at different temperatures. What laws are suggested by the results?

Remarks. — The tubes should be thoroughly cleaned after measuring their diameters, and also after using them with any liquid. *Air-bubbles in the tubes will prevent the liquid from rising to its proper height.* Do not blow through the tube to remove them.

Form of Record. — Tabulate as shown in previous problems, and then summarize work in a table of the following form: —

No. of tube.	Length of mercury filament.	Weight of glass vessel.	Weight of vessel and mercury.	Weight of mercury.	Volume of mercury.	Area of cross-section.	D, or diameter of tube.	Height water rises.	H, or corrected height.	H × D.	Ht. Water rises at 50° C.	Ht. Water rises at 90° C.	Height Alcohol rises.	Height Ether rises.	Height Turpentine rises.
	cm.	g.	g.	g.	ccm.	scm.	cm.	cm.	cm.		cm.	cm.	mm.	mm.	mm.
1	5.186	22.548	23.709	1.161	.085	.0164	.144	2.01	2.034	.293	1.89	1.75	8.05	6.85	8.9
2	6.33	22.548	24.695	2.147	.158	.0250	.178	1.65	1.679	.295					
3	5.44	22.548	23.944	1.396	.103	.0189	.155	1.876	1.902	.299					
etc.															

The data may be represented graphically (6), the diameters of the tubes and the corrected height to which water rises in the tubes being taken as abscissæ and ordinates respectively. Show wherein the curve obtained proves the law of capillarity.

CHAPTER III.

MECHANICS OF SOLIDS.

I. Composition of Forces.

30. Problem. — *To test the rule for finding the resultant of two concurring forces.*

Apparatus. — Three draw-scales reading to grammes, a sheet of paper, a metre of cord, a stout awl, and a protractor.

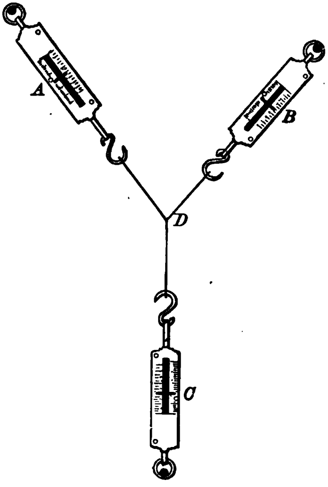

Fig. 21.

Method. — Tie together at one end three stout cords, each about 30 cm. long, and fasten the free ends to the hooks of three balances respectively. Fix two screws some distance apart, near the edge of the table, and over each place a ring of a balance (Fig. 21). Now pull on the third balance in a direction toward the opposite side of the table, till each balance registers several divisions of the scale, and secure it by inserting a stout awl through the ring into the table. There are three forces in equilibrium acting at *D*, any one of the three being equal and opposite to the resultant of the other two. Place a sheet of paper beneath the cords, and mark on it their directions. Measure with the protractor (**17**) the angles between these lines, and record their values as well as the readings of the draw-scales. On the left-hand page of the note-book draw three lines, making with one another the angles just measured and also similarly placed. These lines will represent the directions of the three forces. Then proceed in the usual way to lay off on each line as many units of length as there are units of force indicated by the respective balance. Complete the parallelogram having two of these measured lines as adjacent sides, and draw that diagonal which is concurrent with them. The closeness of agreement between the value of this diagonal and that of the unused line, as well as the closeness of agreement in direction, will measure the success of the experiment. These comparisons should be the chief subject-matter of the discussion.

Remarks. — The experiment should be repeated several times, varying both the forces and the angles between their directions.

Form of Record. — The results may be tabulated as follows: —

	BAL. *A*.	BAL. *B*.	BAL. *C*.	ANGLE *ADB*.	ANGLE *BDC*.	RESULTANT OF *A* AND *B*.	ERROR.
1st Trial,	....	....	....	....	....	....	....
2d "	....	....	....	....	....	....	....
	etc.		etc.		etc.		

31. Problem. — *To test the rule for finding the resultant of several concurring forces.*

Apparatus and Method. — Similar to that of Art. **30.**

32. Problem. — *To test the principle applied in compounding two parallel forces.*

Apparatus. — A wooden rod **1** m. long, a metre-rod, and three draw-scales.

Method. — Insert two stout screws in the table near its edge and 90 cm. apart. Place the ring of a draw-scale over each, and the wooden rod in the hooks of these draw-scales. Hook the third draw-scale on the rod at some point between the other two and on the opposite side. Having the lines of the first two draw-scales parallel, pull on the third one till each balance registers several pounds, and fasten it in position by inserting a stout awl through the ring into the table. Read each balance, and measure the distances between the hooks. Compare the reading of the third balance with the readings of the other two; and also compare the ratio of the readings of the first two with the inverse ratio of the distances of their hooks from the third hook. These comparisons should form the chief subject-matter of the discussion.

Remarks. — The experiment should be tried several times, varying the conditions each time. The forces involved should have their lines of direction parallel both to one another and to the top of the table.

Form of Record. — Tabulate the data as follows: —

	Bal. I.	Bal. II.	Bal. III.	Dist. I to III.	Dist. II to III.	Ratio of Forces.	Ratio of Dist.	Bal. I. + II.
1st Trial,	....	....	....	....	....			
2d "	....	....	....	....	....			
	etc.			etc.		etc.		

II. Curvilinear Motion.

33. Problem. — *To test the laws of curvilinear motion.*

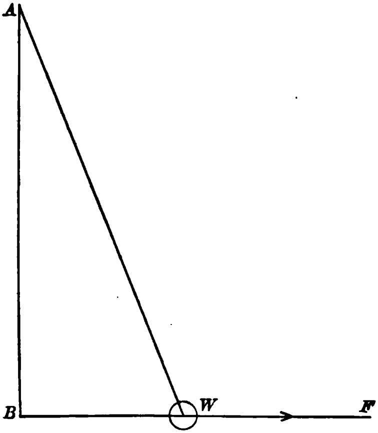

Fig. 22.

Theory. — If a weight, *W*, be suspended from *A* by a wire, *AW* (Fig. 22), and *AW* be made to describe a cone about the vertical *AB*, *W* describing a circle about *B*, then *W* is maintained in its path by a centrifugal force which is equal to that required to maintain the weight at *W* if applied to it in the direction of *BF*.

Apparatus. — A heavy ball weighing several pounds, a draw-scale reading to ounces, a clock marking seconds, and a brass wire 3 m. long.

Method. — Suspend the ball by the brass wire from a hook in the ceiling, and set it swinging in a horizontal circle. Measure as accurately as possible the diameter of the circle described by the ball, and also measure the time, t, occupied in completing the orbit. The latter can be easily done by observing how many seconds it takes in which to make say, ten revolutions. Find by the draw-scale what force is necessary to hold the ball deflected from the vertical, a distance equal to the radius of the path described by it when t was measured. The laws of curvilinear motion are expressed by the formula $F = \frac{Wv^2}{gr}$, in which W is the weight of the moving body, v is its velocity, r is the radius of the circular path described, and g is the acceleration due to gravity, and may be taken as 32.16 ft. To obtain v, divide the circumference of the circular path by the time. Compare F as computed by the above formula with F as obtained by the draw-scale, and discuss the causes of difference.

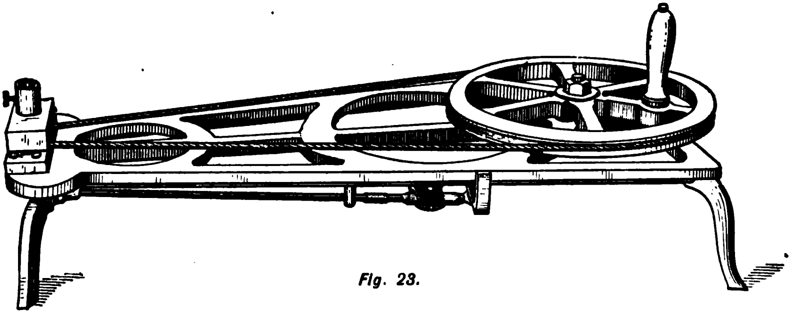

Fig. 23.

Alternative Method. — Attach to the whirling machine, Fig. 23, an apparatus of the form shown in Fig. 24, where a cylinder, in moving away from the axis of rotation in obedience to centrifugal force, lifts a weight. Give the machine a speed sufficiently great to raise the weight a very short distance, and while that speed is maintained, find, with a speed counter,[1] the velocity of the small axis. Measure with the draw-scale the force necessary to pull the cylinder along the wire sufficiently to lift the weight the amount seen in the experiment. Measure the distance of the centre of the cylinder from the axis of rotation when the weight is lifted. Find the weight of the cylinder. Substitute these values in the formula $F = \frac{Wv^2}{gr}$, in which $g = 32.16$ft. The nearness of agreement between the observed F and the computed one will measure the success of the experiment.

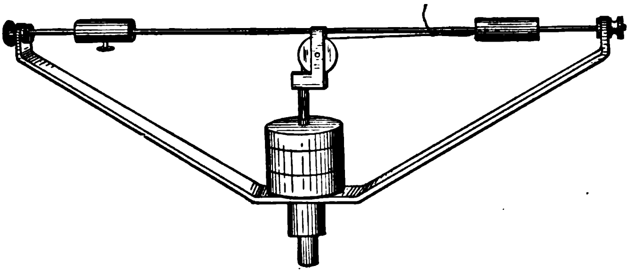

Fig. 24.

Form of Record. — The data obtained by the last method may be tabulated as follows: —

	W.	r.	No. of Revolutions in 10 Seconds.	v.	F Observed.	F Computed.	Error.
1st Trial,	....	....	....	....	....	....	....
2d "	....	....	....	....	....	....	....
	etc.		etc.		etc.		

---

[1] It is a good plan to have the speed counter permanently attached to the axis, as shown in Fig. 23.

III. Accelerated Motion.

34. Problem. — *To test the laws of accelerated motion.*

Apparatus. — An inclined track, a ball, and a seconds pendulum. The inclined track is made by nailing together three straight-edged boards, about sixteen feet long, the edges of the two outside ones projecting an inch beyond that of the middle one, forming with it a rectangular groove. On these projecting faces graduate a centimetre scale. This compound board should be provided with legs, so that the groove will form an inclined track having one end about one foot higher than the other. The ball should have a diameter of about 1.5 inches, and may be of either wood or iron, the latter being preferable. The seconds pendulum may be either a clock which ticks seconds, or a ball suspended by a string of such length as to vibrate seconds.

Method. — Find by trial the distance passed over by the ball in 1 sec., 2 sec., 3 sec., 4 sec. Repeat several times, and obtain the mean. To start the ball, hold it on the groove by resting a finger on top of it, lifting the finger on the tick of the clock. To locate the ball at the expiration of the allotted time, place a heavy rectangular ruler in the groove, and find by trial the position necessary to make the sound from the clock coincident with the impact of the ball against the ruler.

Find from the data obtained the ratio of the total distance passed over at the end of each second to that traversed the first second. Represent the distance traversed during the first second by $\frac{a}{2}$, and then show what formula will represent the total distance traversed at the end of any second. Represent the data by a curve, the times being the abscissæ, and the total distances the ordinates (**6**).

Find from the data the distance traversed during each second, and the ratio of that distance to that passed over during the first second. Then, as above, show what formula will represent the distance traversed during any second. Represent the data by a curve, using the same origin as before.

What is the velocity at the end of each second? Find the acceleration for each second. Is the acceleration constant? Why should it be? How does it compare with the distance traversed during the first second?

What formula expresses the relation found to exist between *velocity*, *acceleration*, and *time?*

Form of Record. — Tabulate results as follows: —

No. of Seconds.	1st Trial.	2d Trial.	3d Trial.	Mean Total Distance, or S.	Distance Each Second, or S′.	Velocity, V.	Acceleration, or a.
....	....	....	....	....	....	....	....
....	....	....	....	....	....	....	....
....	....	....	....	....	....	....	....
....	....	....	....	....	....	....	....

Remarks. — The distance traversed by the ball should be measured from the front surface of the ball at starting to the corresponding surface at stopping, or from the centre of the ball to the centre of the ball in its new position. The discussion should point out what answers the data obtained furnish to the questions asked. It will require considerable practice to be able to start the ball exactly at the tick of the clock, and determine exactly its place on the plane at the moment of any given subsequent tick.

IV. The Pendulum.

35. Problem. —*To test the laws of the pendulum and find the value of g.*

Apparatus. — A lead or iron ball suspended by a thread from a firm frame (Fig. 25), and a clock ticking seconds. The supporting thread should be wedged in a hole passing up through the bar, so that the pendulum will oscillate about a point in the plane of the under face of the bar. A preferable support is a metallic clamp soldered to the projecting arm of a large iron bracket firmly fastened to the side-wall of the room.

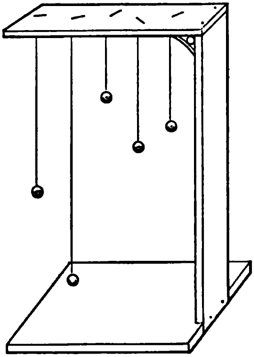
Fig. 25.

In the absence of a clock to mark time, suspend a heavy metallic ball by two fine wires. Solder to the bottom of the ball a short wire. Support beneath the ball, when at rest, an iron block containing a globule of mercury in a small depression. The point of the wire should pass through the globule of mercury at each vibration of the pendulum. Connect one pole of a battery to the iron block, and the other pole through a telegraph sounder to the suspending wire at the point of suspension. Raise or lower the ball till the vibrations are made in one second. *See* App. A. **12**.

Method. — *First.* Set the pendulum swinging through a *small arc*, and find the time of a single vibration. To do this, let one person watch the pendulum till it passes through the lowest point of its arc *coincident* with the tick of the clock, and then count the number of passages through the lowest point till this coincidence is repeated. A second person should count the number of "*ticks*" of the clock made in that interval. In order that the second person may know when to begin counting the "*ticks*," the first one should signal to him by saying "*tick*" at the moment of coincidence. The second coincidence may be made known by speaking aloud the number of the vibration at the time. Several trials should be made, the observers changing places at each trial. In like manner test a *very large arc*. Compare the results, and ascertain what effect the change of amplitude has had on the time of vibration.

Second. Set a long pendulum vibrating through a *small* arc, and determine as before the time of a single vibration. Measure the length of the pendulum, by adding to the distance from the point of suspension to the top of the ball, one-half of the diameter of the ball. In like manner try at least two other lengths. Divide the time in each case by the square-root of the length. These quotients should be equal. What law is suggested?

To compute g, we have $t = \pi\sqrt{\frac{l}{g}}$, from which $t^2 = \pi^2\frac{l}{g}$, and $g = \frac{\pi^2 l}{t^2}$.

Remarks. — The observer should stand directly in front of the pendulum while counting its vibrations, and should have a mark on the wall directly behind the ball when at rest, to aid in determining when the vibrating pendulum passes through the lowest point of its arc.

Form of Record. — Results may be entered as follows: —

	No. of Vibrations.	No. of Ticks.	t.	l.	$t \div \sqrt{l}$.	g.
Small Arc	....	....	....			
	....	....	....			
	....	....	....			
		Mean	....			
Large Arc	....	....	....			
	....	....	....			
	....	....	....			
		Mean	....			
First	....	....	....	....		
Pendulum	....	....	....	....		
	....	....	....	....		
		Mean	....	....	....	....
Second	....	....	....	....		
Pendulum	....	....	....	....		
	....	....	....	....		
		Mean	....	....	....	....
	etc.		etc.		etc.	
					Mean	....

V. The Simple Machines.

36. Problem. — *To test the law of equilibrium of the lever.*

Apparatus. — The apparatus is shown in Fig. 26. It consists of a wooden bar about 27 cm. long, 2 cm. deep, and 1 cm. thick. At distances of 3 cm. each way from the middle are inserted pieces of brass rod about 3 cm. long and 2 mm. in diameter. At the ends of the bar are small adjusting weights to correct for variations in the density of the wood. The weights are lead balls provided with hooks. A scale-pan, pulley, a lead cylinder for counterpoise, a Y-support, and an iron stand complete the outfit.

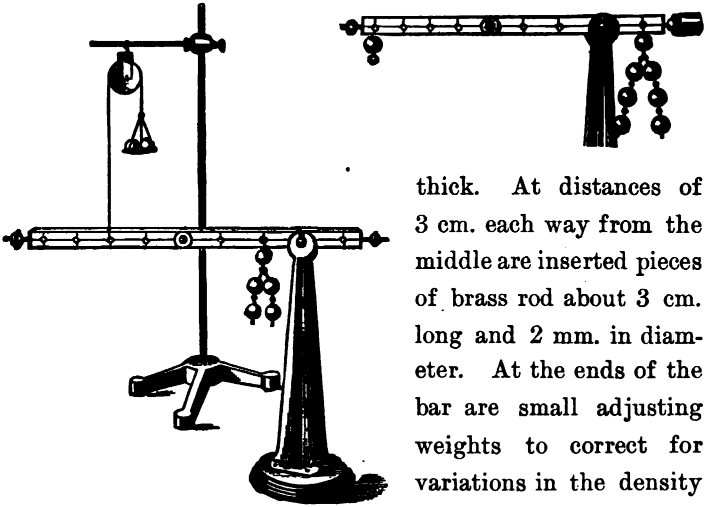

Fig. 26.

Method. — Set up the apparatus as shown in the figure. Counterpoise the lever if necessary, then add weights at two points on opposite sides of the fulcrum, keeping the bar horizontal. Count the number of weights in each case and also the number of spaces that the point of application of each force is distant from the fulcrum. In successive trials vary the distances as well as the weights used. Compute the ratio of the weights, and also the inverse ratio of their arms or distances from the fulcrum. Repeat the experiment, placing both weights on the same side of the fulcrum. The weight of the bar must be neutralized, either by weights in the pan, or by weights placed on the short piece of the bar projecting beyond the Y-support. In the discussion analyze the data, pointing out what conclusions are justified by them.

Form of Record. — Enter results as follows: —

	W.	W′.	D.	D′.	W ÷ W′.	D′ ÷ D.	ERROR.
1st Trial,	....	....	....	....	....	....	....
2d "	....	....	....	....	....	....	....
	etc.		etc.			etc.	

37. Problem. — *To test the law of equilibrium for any given combination of pulleys.*

Apparatus. — Several pulleys, two scale-pans, cord, small shot, and a set of weights or a number of equal small lead balls.

Method. — Set up the combinations shown in Fig. 27. Place shot in one of the pans to counterbalance the weight of the pulleys. Then place known weights in the pans, and ascertain their ratio whenever equilibrium is secured.

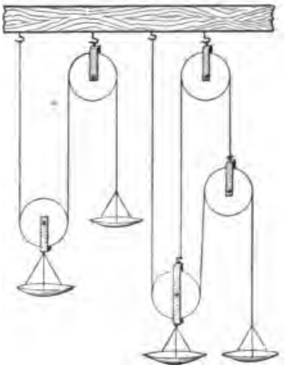

Fig. 27.

Compare this ratio with the inverse ratio of the distance that the weights pass through when displaced vertically. Try other combinations of pulleys. Make a careful analysis of the data, showing what conclusions can be drawn.

Form of Record. — Enter results as follows : —

	W.	W′.	D.	D′.	W÷W′.	D′÷D.	ERROR.
1st Trial,	....	....	....	....	....	....	....
2d "	....	....	....	....	....	....	....
	etc.		etc.		etc.		

38. Problem. — *To test the law of equilibrium of the wheel and axle.*

Apparatus. — A number of cylinders differing in diameter and turning on a common axis (Fig. 28), fine shot, and known weights. To each cylinder is attached a cord to support a scale-pan.

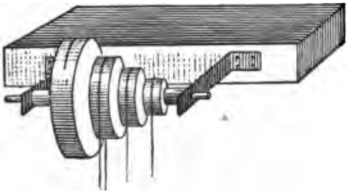

Fig. 28.

Method. — Attach scale-pans to two of the cords, and place fine shot in one till equilibrium is secured. This will neutralize the effect of the pans. Now place known weights in the pans, and ascertain their ratio whenever equilibrium is secured. Compare this ratio with the inverse ratio of the diameters of the cylinders used. Make several trials of each pair of cylinders.

Remarks. — Equilibrium may be considered as secured when the scale-pans move uniformly either up or down on setting them in motion.

Form of Record. — The data may be tabulated as follows: —

	D_1.	D_2.	W_1.	W_2.	$D_2 \div D_1$.	$W_1 \div W_2$.	ERROR.
1st Trial,	....	....	....	....	....	....	....
2d "	....	....	....	....	....	....	....
	etc.		etc.			etc.	

39. Problems. — *To test the law of equilibrium of the inclined plane.*

Apparatus. — A narrow hard-wood plank about 6 ft. long, a spring-balance reading to ounces, a small car or toy carriage capable of carrying a load of 8 or 10 lbs.

Method. — *First Case.* Support one end of the plank so that the surface makes an angle of about 30° with the table. Place a load of, say, 10 lbs. on the carriage, attach the spring-balance, and find what force applied parallel to the surface of the plank moves the load slowly up the plane and with uniform speed. Then let the load move with uniform speed down the plane and at the same rate as it ascended, and ascertain the force applied. If F be the true force required to move the load up the plane, provided there were no friction, and if f be the friction, then $F+f$ will be the reading of the balance when the load is ascending, $F-f$ when the load is descending, and the average of these two readings will be the force required to move the load on the plane if there were no friction. Find the weight of the car, and the load placed upon it; also find the length of the plank, and the difference in height of the two ends. Compare the ratio of the total load moved to the force required to move it with the ratio of the length of the plane to the height. Compute the force required by theory. Make several trials, varying both the load and the height of the plane.

Second Case. Attach a stout wire ring to the carriage, so as to encircle the plank, and make it possible to attach the balance beneath the plank, and apply the force to the load in a horizontal direction. Find, in the same manner as in the first case, the horizontal force necessary to move the load up the plane. Compare the ratio of the load moved to the moving force with the ratio of the length of the base to the height of the plane. Compute the force required by theory. Make several trials.

Remarks. — In reading the spring-balances the line of sight must be normal to the face of the instrument, and the readings must be corrected for any error in the zero of the balance. Make a careful analysis of the data in the discussion.

Form of Record. — Enter results as follows: —

FIRST CASE.

	LENGTH. l.	HEIGHT. h.	LOAD. L.	FORCE. UP. $F+f$.	FORCE. DOWN. $F-f$.	TRUE FORCE. F.	COMPUTED FORCE.	$\frac{l}{h}$.	$\frac{L}{F}$	ERROR.
1st Trial,	.....	.....	......	......	.....	.....	.....	.....	.....	.....
2d "	.....	......	.....	.....	......	......	......	......	.....	.....
	etc.		etc.		etc.			etc.		

SECOND CASE.

	LENGTH. l.	BASE. b.	LOAD. L.	FORCE UP. $F+f$.	FORCE DOWN. $F-f$.	TRUE FORCE. F.	COMPUTED FORCE.	$\frac{l}{b}$	$\frac{L}{F}$.	ERROR.
1st Trial,	......	.....	......	.....	......	.....	......	......	.....	......
2d "	......	......	.....	......	......	......	......	......	......	.....
	etc.		etc.			etc.		etc.		

CHAPTER IV.

MECHANICS OF FLUIDS.

I. Pressure in Fluids.

40. Problem. — *To measure the pressure at any point within a vessel of water, and compare the pressures in different directions at that point.*

Apparatus. — Four glass tubes of the forms shown in Fig. 29, mercury, a pair of dividers, a linear scale, a deep vessel filled with water, and a rubber connector.

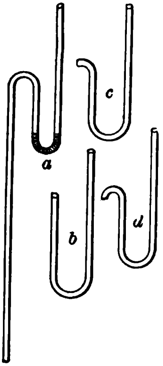

Fig. 29.

Method. — Pour mercury in the U-shaped part of (*a*) till it rises about 1 cm. in each arm. Fill the tube (*b*) with water, connect it to the lower end of (*a*) with a rubber connector, hold it vertically in the vessel of water, and measure the difference of level of the mercury in the two limbs for various distances of the mouth of (*b*) below the surface. Try successively the tubes (*c*) and (*d*), using the same distances of their mouths below the surface as in the case of (*b*). Find the ratio of the depth of the submergence to the corresponding change in mercury level. These ratios should be constant.

Remarks. — The tubes (*b*), (*c*), and (*d*) should be filled with water before connecting them to (*a*). The following questions should be answered in the discussion: What causes the change of mercury level? Proof? What pressure is measured in each case? How do these pressures compare at the same depth?

Form of Record. — Enter results as follows: —

	Depth. h.	Tube (*b*). p.	Tube (*c*). p_1.	Tube (*d*). p_2.	$\frac{h}{p}$.	$\frac{h}{p_1}$.	$\frac{h}{p_2}$.
1st Trial,	....	....	....	....	....	....	....
2d "	....	....	....	....	....	....	....
	etc.		etc.		etc.		

41. Problem. — *To measure the atmospheric pressure.*

Apparatus. — A heavy glass tube about 80 cm. long and closed at one end, mercury, a small glass funnel, a rubber connector, a linear scale, a shallow glass beaker or tumbler, and a wooden support.

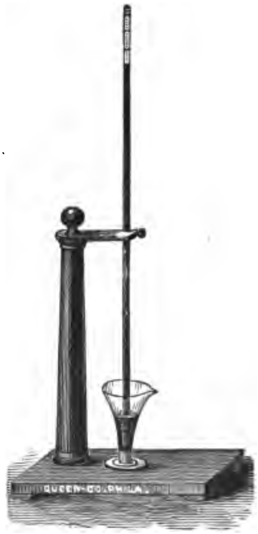
QUEEN-CO. PHILA.

Fig. 30.

Method. — Measure the bore of the tube (**24**). Attach the funnel, and fill the tube with mercury. Close the open end with the finger, invert the tube, place the end in the dish of mercury, and remove the finger. Support the tube in a vertical position (Fig. 30), and measure in centimetres the height of the mercury in the tube above that in the dish. Compute the area of the cross-section of the tube in square centimetres; multiply this by the height of the mercury; the product will be the volume of mercury sustained by the atmospheric pressure. Since 1 ccm. of mercury weighs 13.6 grammes, then the product of 13.6 by the volume will be the atmospheric pressure on an area equal to the cross-section of the tube. This pressure divided by the area will be the pressure per square centimetre.

Remarks. — The mercury should be pure. Air-bubbles should be removed as perfectly as possible. The larger ones can be removed by filling the tube with mercury to within about 2 cm. of the end, closing the end with the finger, and inclining it till the enclosed air moves slowly along the tube to the other end. In its course there and back it will gather to itself many of the air-bubbles adhering to the tube. To remove the air completely, the mercury must be boiled in the tube. This requires special apparatus.

Form of Record. — Enter results as follows: —

	DIAMETER.	AREA.	HEIGHT OF MERCURY.	VOLUME OF MERCURY.	WEIGHT OF MERCURY.	PRESSURE PER SCM.
1st Trial,	....	....	....	....	....	....
2d "	....	....	....	....	....	....
	etc.		etc.		etc.	

42. Problem. — *To measure the vertical distance between the floor of the basement of a building and that of the top story.*

Apparatus. — An **Aneroid Barometer** (Fig. 31) and a tape measure.

Method. — Place the aneroid barometer in a horizontal position on the floor of the basement. Tap the instrument gently with the finger in order to bring the pointer into equilibrium. Read the position of the pointer, expressing the result in inches and hundredths of an inch. Now take the barometer to the floor of the top story, and make similar observations there. Compute the height by the rule that a barometer changes .01 inch for a change of level of 8.7 feet. With a tape or cord, measure the distance and compute the error. Repeat the observations several times.

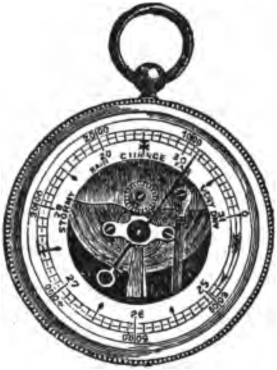

Fig. 31.

Remarks. — The barometer readings at the two levels must be taken at times separated by as short an interval as possible to avoid errors due to a rising or falling barometer. More accurate rules for computing the height will be found in advanced works on Theoretical Physics.

II. Pressure on the Bottom of a Vessel.

43. Problem. — *To prove that the pressure on the bottom of a vessel varies as the depth of the liquid, and is independent of the shape of the vessel.*

Apparatus. — Bend a stout glass tube twice at right angles, making the arms 30 cm. and 12 cm. long respectively, and 40 cm. apart. Set this in a frame with the arms vertical and well supported (Fig. 32). Take a glass tube *A*, 25 mm. in diameter and 25 cm. long, a lamp-chimney *C*, and a two-litre bottle *B*, with the bottom removed; fit to each of them a thick cork with two holes, in which are inserted two pieces of glass tubing, one to be used in attaching the tube to the U-tube, the other to be used in emptying water out of the apparatus.

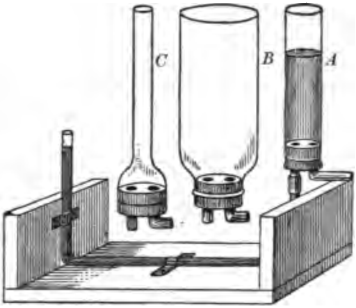

Fig. 32.

Method. — Pour mercury into the U-tube till it stands about 10 cm. high in the long arm. Attach the tube *A* with a rubber connector to the short arm of the U-tube, close the outlet tube with a cork, and pour in water. Measure the depth of the water, and also the change of mercury level. Add more water, and repeat the measurements. Fill *A* with water, and repeat the measurements. Empty *A*, replace by *B* and *C* in succession, and repeat the measurements, employing the same depth of water. Divide the depth of water by the corresponding changes of mercury level for each vessel. The quotient should be constant.

Remarks. — The depth of the water in the vessels should be taken to the surface of the mercury in the short arm.

Form of Record. — Enter the results as follows: —

DEPTH OF WATER. D.	CHANGE OF MERCURY LEVEL. for $A=P$.	CHANGE OF MERCURY LEVEL. for $B=P_1$.	CHANGE OF MERCURY LEVEL. for $C=P_2$.	$\frac{D}{P}$.	$\frac{D}{P_1}$.	$\frac{D}{P_2}$.
....	....	....	....	....	....	....
....	....	....	....	....	....	....
	etc.		etc.		etc.	

III. Law of Boyle.

44. Problem. — *To test Boyle's law for pressure.*

Apparatus. — Two glass tubes A and B, connected by a stout rubber tube C, and attached to a wooden support (Fig. 33). The tube A is closed air-tight by an iron cap; tube B is open. Each tube is clamped to a wooden strip that slides in a groove by the side of a linear scale. The tubes can be fastened at any desired point on the scale. The rubber tube and part of A and B are filled with pure mercury.

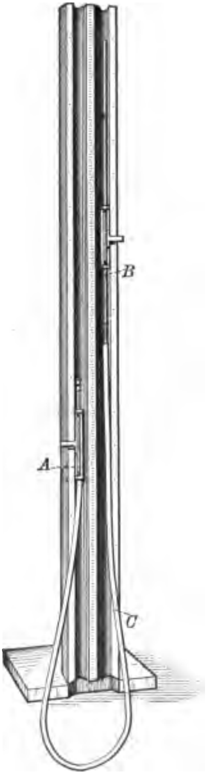

Fig. 33.

Method. — Clamp A and B on the support at points nearly opposite each other. Open A, and adjust the position of B to give 15 or 20 cm. of air in A. The mercury should now stand at the same level in both tubes. Close A; the enclosed air will now be under a pressure equal to that indicated by the barometer. Now slide *B* down as far as possible. The mercury in *A* will fall, but not to the level of that in *B*. The air in *A* will be under a pressure equal to that of the atmosphere less the difference of level of the mercury in *A* and *B*. Move *B* upward, say, 10 cm., and determine the pressure on the air in *A* as before, and also the length of the air-column. Proceed in this way till *B* reaches the top of the support. As *B* moves above *A*, the pressure on the air in *A* exceeds that of the atmosphere by the difference of mercury level. For each position of *B*, it will be necessary to record the length of the air-column in *A*, the position of the mercury in *A* and also in *B*. From these data compute the difference of mercury level, and add it to the barometer reading to obtain the total pressure. The product of the length of the air-column by the corresponding pressure should be constant. Repeat the experiment several times, varying the amount of air in *A*. Compute the volume according to the law, and determine the error of each observation. Represent the results, length of air-column and corresponding pressure, by a curved line (**6**). Analyze the results, and show what inferences are possible. Account for deviations of the data from those indicated by the law, as stated.

Form of Record. — Enter results as follows: —

LENGTH OF AIR COL. OR *V*.	READING OF *A*.	READING OF *B*.	READING OF *Bar*.	TOTAL PRESSURE. *P*.	$V \times P$.	COMPUTED AIR COL.
	Top 67.45					
22 cm.	Bottom 45.45	45.6	74.498 cm.	74.648	1642.26	22 cm.
20.45 cm.	Bottom 47.00	53.4	....	80.898	1654.36	20.30 cm.
19.00 cm.	Bottom 48.45	60.95	....	86.998	1652.96	18.87 cm.
17.65 cm.	Bottom 49.8	68.6	....	93.298	1646.71	17.60 cm.
	etc.		etc.		etc.	

Remarks. — It should be observed that in computing the total pressure when the mercury level in B is below that in A, the difference of mercury level must be treated as a negative quantity.

IV. The Siphon.

45. Problem. — *To prove that the rate of flow of a liquid from a siphon is proportional to the difference of length of the arms.*

Apparatus. — A siphon, a large vessel of water, and a graduate. The siphon may be made by bending a glass tube twice at right angles, making the branches equal and parallel. The branches should be about 50 cm. long, and the vessel of water should be about 40 cm. deep.

Method. — Clamp the siphon with one branch in the vessel of water, with the part connecting the arms horizontal, and about 10 cm. above the water. Measure the length of the arms, the short one being the vertical distance of the highest part of the siphon above the water, and the long one being the vertical distance of the highest point above the outlet. Start the siphon by suction, and measure the amount of flow in two minutes. Raise the siphon, thereby changing the lengths of the arms, and repeat the measurements. Secure four or five variations in the relative lengths of the arms. Divide the amount of flow per minute in each case by the corresponding difference of the arms. Represent the related quantities, amount of flow, and excess of long arm, by a curve (**6**).

Remarks. — The water in the vessel should be maintained at a constant level in order to keep the lengths of the arms constant. Write as a theory to your report the theory of the action of a siphon.

Form of Record. — Enter the results as follows: —

Long Arm.	Short Arm.	Difference. D.	Flow in 2 Minutes.	Flow in 1 Minute. V.	$V \div D$.
....	....	....	....	....	....
....	....	....	....	....	....
	etc.		etc.	etc.	

V. The Principle of Archimedes.

46. Problem. — *To find the measure of the buoyant force.*

Apparatus. — Balance, weights, verniered caliper, and a brass cylinder. The brass cylinder may be cut from a brass rod. It should be about 1.5 cm. in diameter and 2 cm. long. Its ends should be parallel planes, and at right angles to the axis.

Method. — Measure the length and the diameter of the cylinder with the verniered caliper (**13**). Compute the volume of the cylinder in cubic centimetres (Table XIV.). Find the weight of the cylinder in grammes (**22**). Tie a fine thread to the cylinder, and suspend it from the small hook usually found at the top of the bail of the balance-pan. Place a small wooden bench astride of the balance-pan, so as not to interfere with the action of the balance. On this bench place a beaker of ice-water. The cylinder should be submerged in the water when the balance beam is in action. Now find the weight of the cylinder in water, and compute the loss. How much water does the cylinder displace? What is the weight of the displaced water? How does this compare with the loss shown by the balance? What is the amount of the error? Arrange all the data and the results of the computations in a table.

Remarks. — Use as little thread as possible on the cylinder. Remove all air-bubbles adhering to the cylinder when in water. The surface tension of the water will interfere with the freedom of vibration of the balance. Under the head of theory show that there should be a buoyant force and what its magnitude should be.

47. Problem. — *To prove that a floating body displaces its own weight of the supporting liquid.*

Apparatus. — A wooden bar 20 cm. long and 1.5 cm. square, a balance, and a linear scale. Bore a hole in one end of the bar, and introduce enough shot to make the bar assume a vertical position when floating in water.

Method. — Find the weight of the loaded bar in grammes (**22**). Float it in ice-water, and mark accurately the water-line on its edge. Then measure the part submerged, and compute its volume in cubic centimetres (Table XIV.). What is the weight of the water displaced? How does this weight compare with that of the bar? Arrange all the ascertained facts in a concise table. Point out in the report the conditions which govern flotation.

VI. Determination of Density.

48. Problem. — *To find the density of a solid*[1] *heavier than water and insoluble therein.*

Apparatus. — Balance, set of metric weights, thread, beaker, wooden bench, ice-water.

Method. — Suspend the solid by a fine thread from the hook on the bail of the scale-pan, and accurately weigh it. Then weigh it submerged in ice-water as described in Art. **46**. The difference of these two weights is the mass of the water displaced. This difference divided by the density of ice-water will be the volume of the substance. The density of the substance will be its mass divided by its volume. Tabulate the data as directed under the use of the balance.

Remarks. — All adhering air-bubbles must be brushed from the submerged body. It will generally be sufficiently accurate to consider that the density of ice-water is one gramme per cubic centimetre. At the temperature of 20° C., the density of pure water is 0.998213.

49. Problems. — *To find the density of a solid*[1] *lighter than water and insoluble therein.*

---

[1] Insert name of solid in the report.

Apparatus. — Same as in ART. **48**.

Theory. — Let $w =$ the weight of a body in air, $a =$ the weight of a solid in air that would sink the given body in water if attached to it; $b =$ the weight of the sinker in water, and $w' =$ the combined weight of the given body and sinker when attached and submerged in water. Then $w + a$ $=$ the weight of body and sinker in air, $w + a - w' =$ the weight of the water displaced by both when submerged, $a - b =$ the weight of water displaced by the sinker, and $w + a - w' - a + b = w - w' + b =$ the weight of water displaced by the body when submerged. Hence, if the gramme is the unit, $w - w' + b =$ the volume of the body in cubic centimetres, and $w \div (w - w' + b) =$ the density.

Method. — Find, as in ART. **48**, the weight w, of the substance in air; the weight in ice-water, b, of a piece of lead sufficiently large to sink the body if attached to it; and the weight in ice-water, w', of the body and sinker tied together. Then the density $= w \div (w - w' + b)$.

Remarks. — It will be noticed that the weight of the sinker in air is not needed. If the sinker is provided with a sharp point, it can be fastened to the body in many cases, without using a thread.

50. Problem. — *To find the density of a solid*[1] *insoluble in water by means of Jolly's balance.*

---

[1] Insert name of solid in the report.

Apparatus. — Jolly's balance (Fig. 16), and a beaker of ice-water. The balance should be provided with two scale-pans, one suspended beneath the other, the lower one submerged in a vessel of ice-water.

Method. — Weigh the body as directed in ART. **23.** Repeat the weighing with the body on the lower pan, tying it there if necessary. Then proceed as in ART. **48.**

Remarks. — When the body is lighter than water, and does not sink when attached to the scale-pan, a sinker must be employed.

51. Problem. — *To find the density of a solid*[1] *soluble in water.*

Apparatus. — Same as in ART. **48.**

Method. — Proceed as in ART. **48**, substituting for the water a liquid of *known* density in which the body is insoluble. The difference between the weight of the body in air and its weight when submerged in the liquid will be the weight of a volume of the liquid equal to that of the body. This difference divided by the density of the liquid will be the volume of the body. The density will be the quotient of the weight in air divided by the volume.

Remarks. — Rock-salt is insoluble in naphtha, rock-candy and saltpetre in strong alcohol, alum and blue vitriol in oil of turpentine, etc.

---

[1] Insert name of solid in the report.

52. Problem. — *To find the density of a liquid*[1] *by means of the specific gravity bottle.*

Apparatus. — Balance, weights, and **Specific-gravity bottle** (Fig. 34). The specific-gravity bottle is a small flask holding 10, 25, 50, or 100 ccm., closed with an accurately fitting glass stopper, through which is a capillary opening.

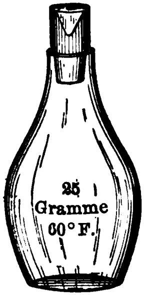

Fig. 34.

Method. — Thoroughly clean the bottle, rinsing it out finally with strong alcohol, and dry it by a current of warm air. Find the weight of the empty bottle. If the volume be not known, fill the bottle with pure water, introduce the stopper carefully, giving the surplus fluid time to escape through the perforation in the stopper. Dry the outside of the bottle with a cloth. Avoid heating the bottle in handling. Find the weight of the filled bottle, and deduct from it that of the bottle; the remainder will be the weight of the water, from which the volume of the bottle is easily obtained. Dry the bottle and fill with the liquid whose density is sought, and find the weight. This weight, less that of the bottle, divided by the volume of the bottle will be the density.

Remarks. — For approximate work, a small Florence flask (Fig. 35) may be used, filling it to a line marked on the neck.

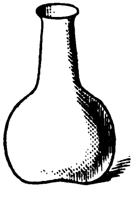

Fig. 35.

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[1] Insert the exact name of the liquid.

53. Problem. — *To find the density of a liquid*[1] *by weighing a solid in it.*

Apparatus. — Balance, weights, a glass stopper or other solid on which the liquid has no chemical action, and a beaker of ice-water.

Method. — Weigh the glass stopper in air and also in ice-water. The difference in grammes will be the volume of the stopper in cubic centimetres. Now find the loss of weight of the stopper in the given liquid. This loss divided by the volume of the stopper will be the density. Why?

54. Problem. — *To find the density of a liquid*[1] *by balancing a column of it against a column of water.*

Apparatus. — A small Y-tube (Fig. 36), two glass tubes 30 cm. long, two small glass beakers, two rubber connectors, a short piece of rubber tubing, a wooden support, and a pinch-cock. Join each glass tube to a branch of the Y-tube. Attach the rubber tube to the stem of the Y-tube, and support the apparatus vertically.

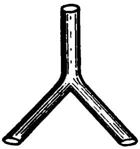

Fig. 36.

Method. — Fill a small beaker with the liquid whose density is sought, and a second one with pure water. Let the tubes of the apparatus dip respectively into these beakers. With dividers or other suitable apparatus measure the capillary effect. By suction remove part of the air from the tubes, and close the rubber tube by the pinch-cock. Atmospheric pressure will force the liquids up the tubes. Measure the heights of the liquids, and subtract that due to capillarity. The density of the liquid will be the height of the column of water divided by that of the liquid.

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[1] Insert the exact name of the liquid.

Form of Record. — Enter results as follows: —

	CAPILLARITY OF WATER.	CAPILLARITY OF LIQUID.	HEIGHT OF WATER.	HEIGHT OF LIQUID.	CORRECTED HEIGHT OF WATER.	CORRECTED HEIGHT OF LIQUID.	DENSITY.
1st Trial,	....	....	....	....	....	....	....
2d "	....	....	....	....	....	....	....
3d "	....	....	....	....	....	....	....

55. Problem. — *To find the density of a liquid*[1] *with Jolly's balance.*

Apparatus. — Jolly's balance, and a solid of two or three cubic centimetres volume on which the liquid has no chemical action.

Method. — Find the weight of the solid in air as directed in ART. **23**. Find its weight when submerged in ice-water, and also its weight when submerged in the given liquid. Then proceed as in ART. **53**.

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[1] Insert the exact name of the liquid.

CHAPTER V.

HEAT.

56. The Bunsen Burner. — When coal-gas is available in the laboratory, the **Bunsen Burner** (Fig. 37) will be found the most convenient and the cheapest source of heat for experimental purposes. It is connected to the gas-pipe by means of a rubber tube. In lighting it, turn on the gas, and as soon as it flows from the mouth of the burner apply a lighted match. Do not hold the lighted match over the mouth of the burner while you turn on the gas, since the gas is likely to take fire down in the tube opposite the lateral openings; it will then burn with a reddish-orange flame, and soon spoil the burner on account of heating the tube. When the air-supply at the holes is properly regulated the flame will be almost colorless, and free from smoke. If too much air is admitted, or if the gas pressure is too low,

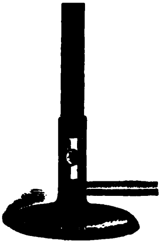
Fig. 37.

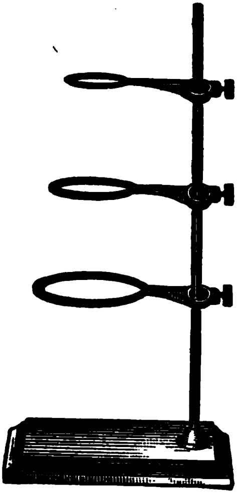
Fig. 38.

the flame may "strike down" the tube, and burn opposite the air-vents. When this occurs the flame should be extinguished, and the burner allowed to cool before relighting.

57. The Iron Stand (Fig. 38) consists of an iron rod fixed vertically in an iron base; clamped to the rod are one or more iron rings. To heat a glass flask or beaker containing any liquid, support it on the ring in a shallow sheet-iron pan whose bottom is covered with dry sand, or what is better, a disk of asbestos paper. The pan, or sand-bath as it is called, should be supported two to three inches above the mouth of the burner. *Never place a cold glass vessel on a hot sand-bath.*

I. The Thermometer.

58. Problem. — *To test the accuracy of the location of the fixed points on the stem of a mercurial thermometer.*

Apparatus. — A mercurial thermometer, a 4-in. funnel, a quart Florence flask, an iron stand, and clean ice.

Method. — To test the freezing-point, support the thermometer in a clamp, and pack ice-shavings around the bulb as far up the stem as the zero-point (Fig. 39). A common glass funnel will be a suit-

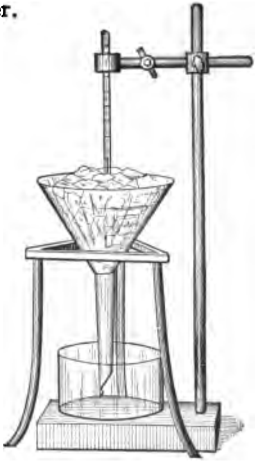
Fig. 39.

able vessel in which to put the ice, since the ice-water can drain off as fast as formed, a very important consideration. After about ten minutes, observe the reading of the thermometer, using a magnifying glass to assist in estimating fractions of a degree.

To test the boiling-point, fill a quart Florence flask a little more than half full of water; support it on the iron stand, and apply heat. Hang the thermometer within the neck of the flask, with its bulb not more than 3 cm. above the water (Fig. 40). The boiling-point on the stem should be about on a level with the mouth of the flask. If the neck of the flask is not long enough for this, a piece of glass tubing, or lamp-chimney, may be supported on the flange of the flask. After steam has been escaping freely from the flask for several minutes, read the thermometer, and at as near the same time as possible read the barometer in the room. Since the boiling-point is affected by the barometric pressure, the true boiling-point can be computed by the following formula, $t = 100° - 0°.0375\ (760 - b)$ in

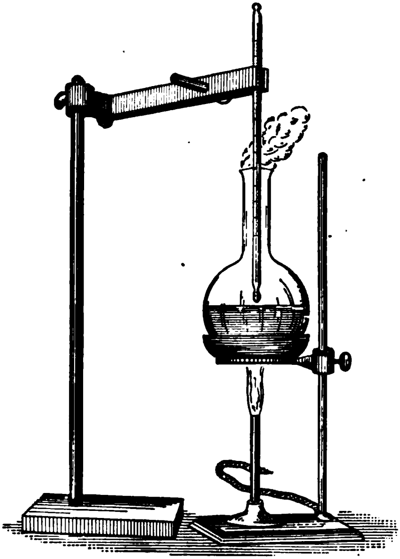

Fig. 40.

which b is the observed barometric reading expressed in millimetres. The error of the instrument will be the difference between the observed and the computed boiling-point.

Remarks. — The ice should be clean, since the presence of foreign matter changes its melting-point. Ice brought in from out-of-doors may be at a temperature below the freezing-point. Hence, it should be shaved up, and allowed to stand till it begins to melt, before packing it around the thermometer. A large, wide-mouthed bottle makes an excellent support for the funnel. In reading the thermometer the *line of sight must be normal to the scale.*

Form of Record. — Enter the results as follows: —

Observed freezing-point, 0°.125 C.; error in freezing-point, 0°.125.

Barometric pressure, 737.87 mm.

Computed or true boiling-point at the time of the experiment, 99°.17 C.

Observed boiling-point, 100°.125 C.; error in boiling-point, 0°.955.

II. Conduction of Heat.

59. Problem. — *To compare the thermal conductivity of several metals.*

Apparatus. — A rectangular tin tank (Fig. 41) provided with small tubes extending from one face, in which are inserted closely-fitting rods of different metals. These rods should be equal in size, being about 5 mm. in diameter, and 10 cm. long.

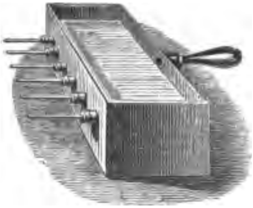

Fig. 41.

Method. — With a small brush, coat the rods evenly with a thin layer of beeswax. Fill the tank with hot water. The heat will be conducted along the rods, melting the wax. As soon as the melting ceases, measure with dividers the distance to which the wax melted on each rod. Make several trials, tabulating the results.

Remarks. — If the wax melts to the outer end of any one of the rods, then the water employed was too hot, and water of lower temperature must be used. The rods should be warmed slightly before attempting to coat them with wax.

60. Problem. — *To compare the thermal conductivity of wood with the grain with that across the grain.*

Apparatus. — A cube of wood about 5 cm. on the edge, a smooth metal ball 2.5 cm. in diameter provided with a handle of stout wire, and a vessel of boiling water.

Method. — Coat uniformly with beeswax three of the faces about one corner of the wooden cube. Heat the metal ball in boiling water, and place it as quickly as possible on the centre of one of the waxed faces of the cube. Any adhering water should be wiped from the ball before placing it on the cube. After the wax has ceased to melt, measure two diameters of the spot taken at right angles to each other, one of them to be the longest diameter of the spot. Also observe the direction of this longest diameter with reference to the grain of the wood. In like manner test the other two faces. Tabulate the results, and point out in the discussion what conclusions are supported by them.

Remarks. — In placing the ball on the cube, it will be necessary to guard against rolling it around on the surface.

III. Radiation.

61. Problem. — *To test the accuracy of Newton's law of cooling, the rate at which the temperature of a cooling body falls by radiation is proportional to the excess of its temperature over that of the surrounding medium.*

Apparatus. — A tin can of about half a litre capacity, a large pail, a thermometer with a very large bulb. A can such as is used for canned fruit may be used, by unsoldering one end and fitting to it a wooden cover, having a hole through its centre large enough to admit the thermometer-bulb (Fig. 42). The inside of the can should be blackened, as well as the under side of the cover, to facilitate the absorption of heat. This can be readily done by holding it above burning gum-camphor, or by applying a thin shellac varnish, blackened by stirring lamp-black into it.

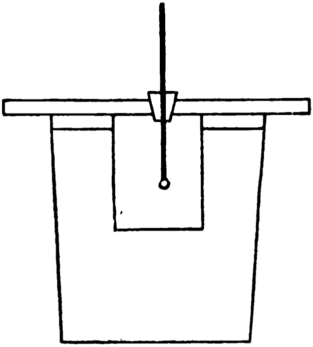
Fig. 42.

Method. — Fit a perforated cork to the cover of the can, and through it pass the stem of the thermometer. The bulb should hang at the centre of the can. The can is designed to exclude air-currents from the cooling body. To maintain the enclosed air at a partially constant temperature, sink the vessel nearly to the top in a large vessel of water. Take the temperature of the water after the can has been in it a few minutes; this will be the temperature of the thermometer chamber, on account of the good thermal conductivity of the can. Now, as quickly as possible, introduce the thermometer within the chamber, having first heated the bulb to about 80° C. by holding it in a dry, hot cloth. Record the reading of the thermometer for every half-minute. In a parallel column, write the difference between these readings and the temperature of the water. These differences will be the excess of the temperature of the bulb or object over that of the surrounding air for each half-minute. In a third parallel column, write the number of degrees that the temperature of the bulb has fallen each half-minute. In a fourth column, place the ratio of the excess to the fall of temperature for each half-minute. If the numbers comprising column four differ but very little, it will show that Newton's law is substantially true.

IV. Expansion by Heat.

62. The Coefficient of Linear Expansion of a body is the fraction of its length which a body expands when heated from 0° to 1° C. **The Coefficient of Cubical Expansion** of a body is the fraction of its volume which a body expands when heated from 0° to 1° C.

63. Problem. — *To determine the coefficient of linear expansion of a metallic rod.*

Apparatus. — A brass rod about 60 cm. long, a thermometer, and a device for heating the rod and measuring its expansion. Fig. 43 shows a convenient apparatus for the purpose. It consists of a wooden frame supporting the rod between two points. The rod is surrounded by a tin tube closed at both ends with thin corks, serving to hold the rod in the axis of the tube. Steam furnished from a copper or glass flask passes into the tube at one end, the condensed water escaping at the other. A thermometer inserted through a stoppered aperture at the centre will give the temperature. One end of the rod rests firmly against a heavy screw in the end support; the other end touches the point of a micrometer screw which passes through the heavy support at that end. These end screws are connected by wires to a battery and galvanometer or electric bell to indicate when contact is made with the rod. The pitch of this micrometer screw must be known, and also the value of the readings on its head.

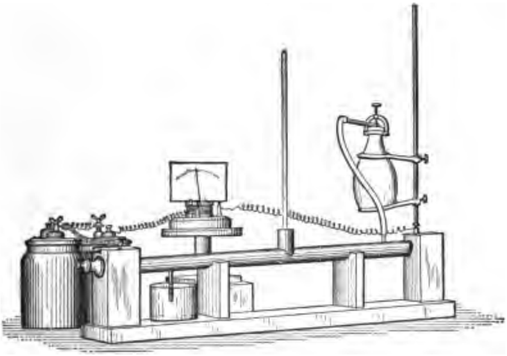

Fig. 43.

Method. — Measure the rod by using a large pair of calipers, or by proceeding as in Art. **15**, first method. This must be done with the greatest possible accuracy. The rod need not be removed from the tube to do this, since it projects just a little beyond the tube at each end. Ascertain the temperature of the rod. Place the rod with its enveloping tube in the supports, and turn the micrometer screw till the moving of the galvanometer needle shows that the screws touch the rod. Record the reading of the micrometer head. Turn the screw backward one complete revolution, so as to give ample room for expansion. Now introduce steam for several minutes, making the time sufficiently long to insure an equilibrium of temperature. Turn the micrometer screw till contact with the rod is again secured, and read the micrometer. The difference between the two readings taken will be the expansion of the rod. This expansion divided by the gain of temperature by the rod will be the expansion for one degree; and this quotient divided by the initial length will be the coefficient sought. *Several trials should be made.* To save time, the rod may be cooled to the temperature of the room by running water through the enveloping tube.

Form of Record. — Enter results as follows: —

	Length.	Initial Temp.	Micrometer Reading.		Expansion.	Final Temp.	Coeff. of Expansion.	Accepted Coeff.	Error.
			1st.	2d.					
1st trial	591.9mm.	18°.33 C	.65	1.49	.84mm.	96°.8 C.	.000018085	. . .	.0000046
2d "	591.9	18°.00	.655	1.52	.865	97°.0	.000018498	.00001875	
3d "	591.9	18°.5	.65	1.50	.85	97°.0	.000018293	. . .	
							.000018292		

64. Problem. — *To determine the apparent coefficient of cubical expansion of a liquid.*

Apparatus. — A glass tube about 15 cm. long and 5 mm. in diameter closed at one end by fusion; a chemical thermometer; a glass or tin tube 25 cm. long, 3 cm. in diameter, closed at one end with a single perforated stopper, and at the other with a triple perforated stopper; ice-water and steam. A retort stand will be needed to support the apparatus. Steam may be supplied as in ART. **63**.

Method. — Fill the tube part full of the liquid to be used, measure the length of the tube, and insert it and the thermometer through the triple perforated stopper. In the other apertures insert short glass tubes. Support the apparatus in a retort stand, close the lower aperture, and fill the supporting tube with ice-water. Adjust the position of the tube containing the liquid so that the surface of the liquid is exactly in the plane of the outer surface of the stopper. Measure the distance from this surface to the open end of the tube, and calculate the length of the liquid column. At the same time record the temperature as shown by the thermometer. Now let the water run out and introduce steam for several minutes. As the liquid expands push the tube through the stopper so that the surface of the liquid is kept in the outer surface of the stopper. When expansion ceases record the temperature, and measure the distance from the surface of the liquid to the open end of the tube. The difference between the two measurements will be the expansion. This expansion, divided by the change of temperature, will be the expansion per degree. The apparent coefficient of expansion will be the quotient of the expansion per degree by the initial length of the liquid column.

Remarks. — For liquids with a boiling-point under 100° C. steam cannot be used. In that case hot water may be employed, regulating the temperature to suit the liquid. The coefficient obtained is evidently less than the real expansion, since the expansion of the glass causes the volume to stand lower in the tube than it would have stood if the glass had not expanded. The real expansion will be the apparent expansion increased by the expansion of the glass, or .0000258. The stopper should be cut away as much as possible from the tube, so that as little of the liquid as possible is cut off from the source of heat.

Form of Record. — Enter the data as follows: —

TRIAL.	LIQUID.	LENGTH OF GLASS TUBE.	DIST. FROM LIQUID TO OPEN END AT —° C.		DIST. FROM LIQUID TO OPEN END AT —° C.		LENGTH OF LIQUID AT —° C.		EXPANSION OF LIQUID FOR —° C.		APPROX. COEFF. OF CUB. EXP.	COR'TED FOR EXP. OF TUBE.
1st	Glycerine	32.333^{cm}	15.78	1°.75	15.	99°	16.553	1°.75	.78	97°.25	.0004845	.000510
2d	Glycerine	32.333	15.80	2°.0	15.03	99°	16.533	2°.0	.77	97°.0	.0004801	.000506
3d	Glycerine	32.333	15.81	2°.0	15.04	99°	16.523	2°.0	.77	97°.0	.0004804	.000506
											Mean,	.000507

65. Problem. — *To determine the apparent coefficient of cubical expansion of air, under a constant pressure.*

Apparatus. — A chemical thermometer, a glass tube of uniform bore, 1 mm. internal diameter, and 25 cm. long, closed at one end by fusion; a glass or tin tube about 25 cm. long, 3 cm. in diameter, closed at each end with a double perforated stopper; ice-water and steam. A retort stand will be needed to support the apparatus. Steam may be supplied as in Art. **63**.

Method. — Introduce into the closed tube a filament of mercury about 10 mm. long. This may be done by warming the tube and dipping the open end into mercury. By means of a fine iron wire the filament may be moved along the tube till the enclosed air-column has the desired length, about 15 cm. Measure the length of the tube and of the mercury filament. Pass this tube through one of the double perforated stoppers of the large tube, the thermometer through the other stopper, and short pieces of glass tubing in each of the other apertures. Support the apparatus horizontally, and fill it with ice-water. After a few minutes adjust the air-column till the outer face of the mercury index is in the outer face of the stopper. Record the temperature, measure the distance from the mercury to the open end of the tube, and compute the length of the air-column. Now remove the water and introduce steam for several minutes. As the air expands, keep the mercury index even with the face of the stopper by pushing in the tube. It may be necessary to tap the tube gently to aid the movement of the mercury index. When expansion has apparently ceased, record the temperature and measure the distance from the mercury to the open end of the tube. The difference between the two positions of the mercury index with respect to the open end of the tube will be the expansion of the air-column. This expansion, divided by the change of temperature, will be the expansion per degree; and the apparent coefficient will be the expansion per degree divided by the initial length of the air-column. To obtain the real coefficient of cubical expansion, this must be increased by .0000258, as in the last problem.

Remarks. — The stopper must be cut away as much as possible from the tube, so that as little as possible of the air-column is enclosed in the stopper.

Form of Record. — The data may be tabulated as follows: —

	LENGTH OF GLASS TUBE.	LENGTH OF MERCURY INDEX.	DISTANCE FROM INDEX TO END AT —° C.	DISTANCE FROM INDEX TO END AT —° C.	LENGTH OF AIR-COL. AT —° C.	EXP. OF AIR COL. FOR —° C.	APPROX. COEFF. OF EXP. AT BAR.PRES. —	ERROR.
1st trial	....	....	....	....	....	....	....	....
2d ”	....	....	....	....	....	....	....	....
3d ”	....	....	....	....	....	....	....	....

V. Melting and Boiling Points.

66. Problem. — *To determine the melting-points of such substances as tallow, lard, paraffine, beeswax, etc.*

Apparatus. — A chemical thermometer, glass beaker, iron stand, Bunsen burner, capillary glass tubes of thin wall and about 1 mm. internal diameter. A suitable capillary tube may be made by softening a piece of ordinary glass tubing in a Bunsen flame and then drawing it out.

Method. — Melt some of the substance in a suitable vessel, and fill the capillary tube by suction. Close one end of the tube by fusion in a gas flame. On cooling, there should be a fine opaque thread of the substance in the tube. Tie this to the thermometer with the bulb and substance side by side. Place a small glass beaker nearly full of water on the sand-bath over the Bunsen flame. When the temperature of the water is near the melting-point of the substance, *stir it gently* with the thermometer, watching closely for any change in the appearance of the contents of the tube. On melting, it loses its opacity; at the moment that this change is observed, the reading of the thermometer must be noted. Now let the water cool, and record the temperature at which opacity returns. Repeat several times, and find the average of the results.

Form of Record. — Enter results as follows: —

	SUBSTANCE.	MELTING-POINT.	CONGEALING-POINT.	MEAN OF MEANS.
1st trial,	Spermaceti	46° C.	45°.5 C.	44°.4 C.
2d "	"	43°.5	42°.2	
3d "	"	45°.0	44°.5	
Mean		44°.8	44°.1	

67. Problem. — *To find the boiling-point of a liquid.*

Apparatus. — A test-tube about 25 mm. in diameter, a double perforated cork, a thermometer, beaker, iron stand, and Bunsen burner.

Method. — Insert the thermometer in one of the holes of the cork, and a glass tube bent at right angles in the other to serve as an escape for the vapor (Fig. 44). Pour about 15 ccm. of the liquid to be tested into the test-tube, insert the cork, and adjust the thermometer so that its bulb is at least two centimetres above the liquid. Hold the tube in a beaker of hot water or linseed oil. The temperature of the heating-bath should not be many degrees above the boiling-point of the liquid. The test-tube should be submerged in the bath as far as the liquid reaches up the tube. When the vapor escapes freely from the bent tube, note the reading of the thermometer and also that of the barometer. Since the boiling-point of a liquid increases 0°.0375 C. for an increase of one millimetre in the atmospheric pressure, hence, to obtain the boiling-point at a pressure of 76 cm., the observed boiling-point must be increased by 0°.0375 (760 — *b*), in which *b* is the barometric pressure expressed in millimetres at the time that the experiment was performed.

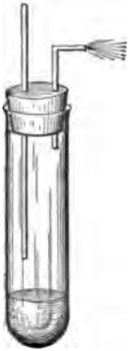
Fig. 44.

Remarks. — Liquids whose boiling-points are above 100°C. will have to be heated in a bath of linseed oil. Very combustible liquids, like ether, must be boiled at a considerable distance from lighted lamps. If pieces of crumpled tin-foil be placed in the test-tube, the boiling will be more regular. Platinum-foil may be used with those liquids which would act chemically on the tin-foil.

Form of Record. — Enter the results as follows: —

	Liquid.	Observed B. P.	Bar. Pres.	B. P. at 76 cm.	Error.
1st trial,	Benzol	80° C.	741.98 mm.		
2d "	"	79°.9			
3d "	"	80°			
Mean		79°.97		80°.65	0°.21

VI. Calorimetry.

68. A Calorie is the quantity of heat necessary to raise the temperature of a gramme of water 1° C.

The Thermal Capacity of a body is the number of calories of heat necessary to raise its temperature 1° C.

The Specific Heat of a substance is the number of calories of heat necessary to raise the temperature of one gramme of the substance 1° C.

69. Problem. — *To determine the water equivalent of a vessel; that is, to find how much water will equal it in capacity for heat.*

Apparatus. — A copper or tin beaker of about one litre capacity, a thermometer, a supply of warm water, a heavy balance, and a set of metric weights.

Method. — Dry the beaker thoroughly, and let it come to the temperature of the room, which will be known by the thermometer reading the same when in contact with it as when suspended near it. Weigh out in a second vessel about 600 g. of water whose temperature is about 60° C. Place this vessel of water on the table, ascertain its temperature, then wait *exactly* one minute and again note its temperature. *Now, with as little delay as possible,* pour the water into the beaker, introduce the thermometer, and record the temperature at the expiration of thirty seconds, and also at the end of the following minute. The fall of temperature during the first minute was due solely to radiation; that during the next thirty seconds was due to absorption by the vessel as well as to radiation; that during the last minute was due to radiation, it being assumed that thirty seconds were necessary to complete the act of absorption. If, however, it is found that the fall during the last minute is considerably more than during the first minute, the time allowed for absorption is probably too short. The fall during the last minute should be but a very little less than that recorded for the first minute. The average of the fall in temperature for the first and the last minute will be the radiation per minute. This, multiplied by the time in minutes allowed for absorption, will be the correction to be added to the observed temperature at the end of the absorption period. The sum will be the temperature of the water and also of the containing beaker, if there had been no radiation. The number of calories of heat consumed by the beaker will be the product of the number of grammes of water by the difference between the temperature of the water when poured into the beaker and its temperature after absorption corrected for radiation. This product divided by the gain of temperature on the part of the beaker will be the number of calories necessary to heat the beaker 1° C., and hence will be the number of grammes of water to which the beaker is equivalent.

Remarks. — In taking the temperature of water, the thermometer must be moved around in the water to mix it up; since its temperature may not be the same everywhere, owing to the poor conductivity of the water. The error of the experiment is easily calculated, since the true equivalent of the beaker is equal to the mass of the beaker in grammes multiplied by the specific heat of the substance of which the beaker is composed. If it is not convenient to weigh the water used, very good results can be obtained by measuring the water when cold in a metric graduate, and then heating it to the required temperature.

Form of Record. — Enter results as follows : —

		1st Trial.	2d Trial.	3d Trial.
(*a*)	Mass of beaker	311 g.	....	....
(*b*)	Temp. of beaker at beginning	21°.5 C.	....	....
(*c*)	Mass of water used	700 g.	....	....
(*d*)	Temp. of water at beginning	57° C.	....	....
(*e*)	Temp. of water after lapse of 1 min.	55°.8 C.	....	....
(*f*)	Temp. of water at end of absorption	54°	....	....
(*g*)	Time allowed for absorption	.5 min.	....	....
(*h*)	Temp. of water at end of next minute	53°.4 C.	....	....
(*i*)	(*f*) corrected for radiation	54.45	....	....
(*k*)	Calories absorbed by beaker $(e - i) \times c$,	945	....	....
(*l*)	Temp. gained by beaker $(i - b)$	32.95	....	....
(*m*)	Thermal capacity of beaker $(k \div l)$	28.68	....	....
	Mean thermal capacity		....	
	True thermal capacity		29.51	
	Error		....	

70. Problem. — *To determine the specific heat of a solid.*

Apparatus. — A beaker whose water equivalent is known, a thermometer, an iron stand, a Bunsen burner, and a vessel of boiling water.

Method. — Make a loose coil of a known weight of the substance, about 200 or 300 g., in sheet or wire form, and suspend it by a thread in boiling water for a sufficient time to acquire the temperature of the water. The temperature of the boiling water must be observed. Pour into a beaker of known water equivalent a known mass of water of the temperature of the room, and of sufficient amount, about 500 g., to cover the coil entirely when placed within it. Now transfer to it the heated coil, stir the water gently with a thermometer, and record the reading when it *ceases to rise*, and also *the time* occupied in equalizing the temperatures. Continue to stir the water for one minute longer, and record the temperature. This last observation is for the purpose of determining the effect of radiation. Half of the fall during this last minute multiplied by the time occupied in securing equalization must be added to the observed temperature to give the correct temperature to which the water was raised by the coil. Add to the mass of water used the water equivalent of the beaker, and multiply this by the gain in temperature; the product will be the number of calories of heat imparted by the coil to the water and beaker. This product divided by the number of degrees lost by the coil will give the coil's capacity for heat; the specific heat of the substance will be the quotient of its thermal capacity by its mass expressed in grammes.

Remarks. — The coil should be suspended in the boiling water in such a manner that, on lifting it out, as little water as possible will be removed by it. Guard against loss of time in transferring the coil. If the solid is soluble in water, a liquid of known specific heat, in which the solid is not soluble, must be selected.

Form of Record: — Enter results as follows: —

		1st Trial.	2d Trial.	3d Trial.
(*a*)	Water equivalent of beaker	29.01	....	....
(*b*)	Mass of water used	500.	....	....
(*c*)	Temp. of water	25°.5 C.	....	....
(*d*)	Mass of coil (zinc)	143 g.	....	....
(*e*)	Temp. of coil	94 C.	....	....
(*f*)	Temp. of water when ther. ceased rising	27° C.	....	....
(*g*)	Temp. of water after lapse of 1 min. . .	26°.8 C.	....	....
(*h*)	Time occupied in equalizing temp. . .	1.5 min.	....	....
(*i*)	(*f*) corrected for radiation	27°.15 C.	....	....
(*k*)	Calories lost by coil $(i - c) \times (a + b)$.	872.87	....	....
(*l*)	Thermal capacity of coil, $k \div (e - i)$.	13.057	....	....
(*m*)	Specific heat of coil $(l \div d)$	.0913	....	....
	Mean		....	

71. Problem. — *To determine the specific heat of a liquid.*

Apparatus. — The same as used in Art. **70**.

Method. — Proceed as in Art. **70**, with the exception that a known quantity of the liquid is used instead of water. Correct the data for radiation, and find the fall of temperature on the part of the coil, as well as the increase on the part of the liquid. The specific heat of the coil must be known, and may be found experimentally (**70**) or by consulting Table XII. The mass of the coil is also known. Then the number of calories of heat imparted to the liquid will be the product of the mass of the coil, by its fall of temperature, by its specific heat, diminished by the product of the water equivalent of the beaker by its increase of temperature. This remainder divided by the liquid's increase of temperature will be the liquid's thermal capacity. The specific heat will be the quotient of the thermal capacity by the mass of liquid used.

Remarks. — The coil should not be heated to the boiling-point of the liquid. A coil must be chosen that is not soluble in the liquid.

Form of Record: — Enter results as follows: —

		1st Trial.	2d Trial.	3d Trial.
(*a*)	Water equivalent of beaker	25.85 g.	....	....
(*b*)	Mass of liquid used (alcohol)	193 g.	....	....
(*c*)	Mass of coil	52 g.	....	....
(*d*)	Specific heat of coil	.0858	....	....
(*e*)	Temp. of liquid at beginning	23°.8 C.	....	....
(*f*)	Temp. of coil	95° C.	....	....
(*g*)	Temp. of liquid when ther. ceased rising	26° C.	....	....
(*h*)	Temp. of liquid at end of next minute .	25°.7 C.	....	....
(*i*)	Time required for equalization of temp. .	1¼ min.	....	....
(*k*)	(*g*) corrected for radiation	26°.1875 C.	....	....
(*l*)	Liquid's increase of temp. $(k - e)$ . .	2°.3875 C.	....	....
(*m*)	Coil's loss of temp. $(f - k)$	68°.8125 C.	....	....
(*n*)	Calories imparted to liquid, $c \times m \times d - a \times (k - e)$	245.2969	....	....
(*o*)	Thermal capacity of liquid, $n \div l$ . . .	102.742	....	....
(*p*)	Specific heat of liquid, $o \div b$	0.5323	....	....
	Mean specific heat of liquid		....	

72. The Latent Heat of Fusion of a solid is the number of calories of heat required to melt one gramme of that substance without raising its temperature. **The Latent Heat of Vaporization** of a substance is the number of calories of heat required to change one gramme of the substance at its boiling-point into vapor at the same temperature.

73. Problem. — *To determine the latent heat of fusion of water.*

Apparatus. — A beaker of known water equivalent, a thermometer, an iron stand, a Bunsen flame, and a supply of clean ice.

Method. — Pour into a beaker a known quantity of water, say 500 g., and raise its temperature to, say, 70° C. Set the beaker on a board, and record the temperature. After stirring slowly with the thermometer for one minute, record the temperature. Now add ice in small pieces till about 200 g. have been introduced, constantly stirring the water with the thermometer. Each piece of ice should be wiped with a dry cloth before putting it into the beaker, to avoid introducing water. The time occupied in putting in the ice should be as short as possible. As soon as the ice is melted, take the temperature of the water, and record the time required to melt the ice. Continue the stirring one minute longer to obtain data for the radiation correction. The exact amount of ice introduced is to be found by obtaining the increase of weight on the part of the beaker and contents.

Form of Record. — The following example will show the method of keeping the record and of making the computation : —

Amount of water in beaker	500 g.
Temperature of water	75° C.
Temperature of water at end of one minute	73°.5 C.
Temperature of water taken as soon as ice melted	32° C.
Temperature of water at end of next minute	31°.5 C.
Time required to melt the ice	3 min.
Amount of ice introduced	179 g.
Water equivalent of beaker	34 g.

Data corrected for radiation and absorption: —

Amount of water, $500 + 34 = 534$ g.

Temperature of water before introducing ice, 73°.5 C.

Temperature of water after ice melted, $32 + 3\left(\frac{1.5 + .5}{2}\right) = 35°$ C.

$534\ (73.5 - 35) = 20559$ calories of heat consumed.

$179 \times 35 = 6265$ calories of heat consumed in raising the ice from 0° to 35°;

$\therefore\ 20559 - 6265 = 14294$ calories of heat consumed in melting 179 g. of ice.

$\therefore\ 14294 \div 179 = 79.9$ calories of heat consumed in melting one gramme of ice.

Other trials may be recorded in columns parallel to this one. See record of Art. **69**.

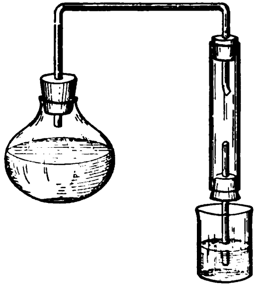

Fig. 45.

74. Problem. — *To determine the latent heat of vaporization of water.*

Apparatus. — A Florence flask of one litre capacity, a delivery-tube of the form shown in Fig. 45, a beaker of known water equivalent, a thermometer, an iron stand, and a Bunsen flame. The large piece of tubing inserted in the delivery-tube is called the "trap," and is designed to retain the water produced by the steam that condenses before reaching the water in the beaker.

Method. — Fill the flask half full of water, support it on the iron stand, and apply heat. In the beaker put a known quantity of water, say, 400 g., at the temperature of the room. As soon as a strong jet of steam issues from the delivery-tube, introduce it into the water in the beaker, letting it reach nearly to the bottom. Place a screen of cardboard between the beaker and the flame. Stir the water constantly and gently with the thermometer; and, when the temperature has risen a certain number of degrees, as 20°, quickly remove the delivery-tube, record the temperature of the water, and the time occupied in introducing the steam. Continue to stir the water one minute longer to obtain the fall due to radiation. Finally, ascertain the amount of steam introduced by determining the increase in weight on the part of the beaker and contents, and also the temperature of the steam by suspending the thermometer within the flask.

Form of Record. — The following example will show the method of making the record and the computation : —

Amount of water in beaker	400 g.
Water equivalent of beaker	9 g.
Temperature of water in beaker	17° C.
Temperature of water after admitting steam	37° C.
Temperature at end of next minute	36°.5 C.
Time consumed in admitting steam	4.67 min.
Amount of steam condensed	14.5 g.
Temperature of steam	99°.175 C.

Temperature of water in beaker corrected for radiation

$$37 + \frac{0.5}{2} \times 4.67 = 38^\circ.17 \text{ C.}$$

Amount of water corrected for beaker equivalent . . 409 g.

409 × (38.17 − 17) = 8658.53 calories of heat imparted to the water.

14.5 (99.175 − 38.17) = 884.5725 calories of heat derived from the water produced by the steam in condensing and cooling from 99°.17 C. to 38°.17 C.

8658.53 − 884.5725 = 7773.9575 calories of heat derived from 14.5 g. of steam condensing to water at the boiling-point.

Hence 7773.9575 ÷ 14.5 = 536.13 calories of heat latent in one gramme of steam.

Other trials may be recorded in columns parallel to this one. See ART. 69.

CHAPTER VI.

MAGNETISM AND ELECTRICITY.

I. Magnetism.

75. Problem. — *To study the action between magnetic poles.*

Apparatus. — Two large needles, a magnet, a flat cork, and a dish of water.

Method. — Magnetize each needle by stroking it from end to end with one of the poles of the magnet. This stroking should always be done in the one direction, the magnet being carried back through the air. Float each needle in succession on the cork, and determine its N-seeking pole. While one needle is floating on the cork, bring the N-seeking pole of the other needle to its N-seeking pole, and record the effect; bring it to the S-seeking pole; bring its S-seeking pole to each pole of the floating magnet in succession.

Form of Record. — Tabulate the observations as follows : —

	EFFECT ON N-SEEKING POLE.	EFFECT ON S-SEEKING POLE.
N-seeking pole bro't up	....	....
S-seeking pole bro't up	....	....

76. Problem. — *To find the position of the poles of a bar magnet.*

Apparatus. — A bar magnet, a sheet of paper, a short magnetic needle, mounted as shown in Fig. 46, or a pocket compass.

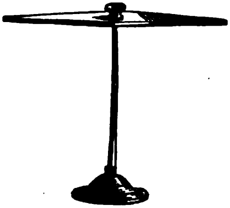

Fig. 46.

Method. — Lay the magnet on the sheet of paper and trace its outline. Support the paper with the magnet on it so that the plane of the paper coincides with that of the needle and with the N-seeking pole of the magnet toward the north. Place the magnetic needle near one corner of the magnet. Stick two pins vertically in the paper about three or four centimetres apart and exactly in line with the two poles of the needle. Now move the needle to the other corner of the magnet, and locate two pins in the same manner as before. Remove the magnet, and draw lines through each pair of points marked by the pins. The intersections of these lines will be situated very nearly under the pole of the magnet. In like manner locate the other pole. Record the dimensions of the magnet and the distance of each pole from the end. Transfer the figure obtained to the left-hand page of the note-book.

77. **Problem.** — *To compare the action of magnetic force through sheets or plates of various substances.*

Apparatus. — Thin sheets of cardboard, wood, glass, zinc, copper, brass, iron, etc., about 10 cm. square, bar magnet, a **Magnetoscope** (App. A. 5), and a watch.

Method. — Set the magnetoscope vibrating through a small arc by bringing a bar magnet near it, and count the number of vibrations it makes in a minute. All magnets must be kept at considerable distance while counting. The vibrations that the needle now makes will be due to the magnetism of the earth. Now support the N-seeking pole of a magnet near the S-seeking pole of the needle, and count the number of vibrations as before. Count the number made when a sheet of cardboard is held between the magnet and the needle. Try in succession sheets of wood, glass, zinc, iron, etc. Compare two sheets of iron, one thicker than the other. To get the number of vibrations made by the magnetic needle the mean of at least three trials should be taken. The distance between the magnet and the vibrating needle should be the same for each trial. If any intercepted sheet is accompanied by a sensible decrease in the number of vibrations as compared with the number obtained when the earth is the sole cause, then that sheet is not perfectly transparent to the magnetic force.

Remarks. — In the successive trials start the needle vibrating through the same arc as nearly as possible. Adjust the magnetoscope so that the needle is in the magnetic meridian. The distance of the magnet from the magnetoscope may be from 2 cm. to 8 cm., according to the strength of the magnet.

Form of Record. — Tabulate the results as follows : —

	EARTH.	AIR.	MICA.	WOOD.	GLASS.	THIN IRON.	THICKER IRON.
	22	68	68	68	68	50	48
	22	70	68	68	66	48	46
	24	68	68	68	66	50	46
Mean	22.7	68.7	68	68	66.7	49.3	46.7

78. Problem. — *To compare the strength of the poles of a bar magnet.*

Apparatus. — A bar magnet and a box of iron carpet-tacks.

Method. — Insert the magnet vertically into the box of tacks, and record the number it lifts. Repeat several times, with as little variation of the conditions as possible. Try the other pole of the magnet in the same way. The ratio of the average of the number of tacks lifted by the two poles will represent approximately their relative strengths.

Remarks. — If the ends of the magnet differ in shape or area, the strengths of the poles cannot be accurately compared by comparing their lifting powers. The method of Art. **79** gives more reliable results.

79. Problem. — *To represent by a curve the change in the magnetic strength as you go from the poles of a magnet to its centre.*

Apparatus. — A carefully magnetized knitting-needle and a **Magnetoscope** (App. A. **5**). To magnetize the needle, wind on it evenly and smoothly, from end to end, a layer of insulated copper wire, No. 19, and send an electric current through it from a battery.

Method. — Adjust the magnetoscope so that its needle points north and south. Produce a small displacement of the needle by bringing a magnet near it, and count the number of vibrations it makes in a minute. Repeat several times, recording the number of vibrations. The average of these numbers will be the numbers of vibrations that the needle makes while vibrating under the influence of the earth. While making these trials, all magnets must be kept at a distance of several feet from the magnetoscope. Divide the needle into eight equal parts by tying threads about it. Divide the end divisions into two equal parts by threads, making eleven points marked on the needle, counting the ends. Now ascertain which is the N-seeking pole of the knitting-needle, and mark it. Support the needle vertically with its N-seeking pole on the south side of the magnetoscope, exactly in line with the axis of the magnet, and distant from the magnet about 4 cm. Ascertain, as before, the number of vibrations made by the magnetoscope-needle in one minute, making several trials and obtaining the average. In a similar manner test each point marked on the knitting-needle. When the number of vibrations becomes less than the number obtained when the magnetoscope was influenced by the earth alone, move the needle to the north side of the magnetoscope. The bringing of like poles together must be avoided, so that attraction and not repulsion may actuate the instrument. The same distance between the needle and the magnetoscope must be maintained throughout, and the positions of the points tested with reference to the end of the needle must be carefully determined and recorded.

Since the vibrating needle is a pendulum, it is subject to the law of the pendulum; that is, the force which actuates it is proportional to the square of the number of vibrations.

Hence, square the number of vibrations for each point of the knitting-needle, and subtract the square of the number due to the earth alone; the remainders will represent the relative magnetic intensities at these points.

To obtain the curve, draw a straight line 10 cm. long to represent the magnet. At points situated at the same relative distance apart as those tested on the magnet, erect perpendiculars; those on one half to be drawn above the line, those on the other, below. On these perpendiculars lay off distances proportional to the numbers representing the magnetic intensities at these points. The scale chosen should be such as to make the distances at the poles about 2 cm. Sketch a smooth curve through the points located. This curve will represent the magnetic intensity at different points along the magnet. Cross-section paper may be used as in ART. **6**, the distances of the points from one end of the needle being the abscissae, and the values of $N^2 - E^2$ being the ordinates.

Remarks. — The magnetoscope should be made to vibrate as nearly as possible through the same sized arc in the successive trials.

Form of Record. — Enter results as follows: —

	EARTH E.	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.
First trial	16.0	30.0	30.5	29.5	25.0	19.75	16.0	25.0	27.0	30.0	32.0	28.5
Second "	16.5	29.5	31.5	29.0	25.0	19.25	16.0	26.0	27.0	30.0	31.5	28.0
Third "	17.0	31.0	31.75	28.5	24.75	19.5	16.0	25.0	27.0	30.0	31.0	29.0
Mean or N. .	16.5	30.2	31.25	29.0	24.9	19.5	16.0	25.3	27.0	30.0	31.5	28.5
N^2	272.25	912.04	976.56	841	620.01	380.25	256	640.09	729.0	900.0	992.25	812.25
$N^2 - E^2$....	....	639.79	704.31	568.75	347.76	108.0	—16.25	367.84	456.75	627.75	720.0	540.0
$\frac{N^2 - E^2}{319.895}$....	....	2.0	2.2	1.78	1.09	.34	—.05	1.15	1.43	1.96	2.25	1.69

319.895 is ½ of 639.79.

80. Problem. — *To map out the magnetic field of a magnet.*

Apparatus. — Bar magnets, horseshoe magnet, white paper, a dish of iron filings, and a thin muslin bag.

Method. — Place the magnet beneath a stiff sheet of paper, and sift iron filings evenly over it from the thin muslin bag, tapping the paper gently to facilitate the movements of the filings. Copy the figure obtained in the note-book, either by means of a pencil or by one of the methods given below. Diagrams for the following should be obtained: a bar magnet, two bar magnets placed with like poles about 5 cm. apart, two bar magnets with unlike poles about 5 cm. apart, a bar magnet supported vertically, a horseshoe magnet.

Remarks. — Permanent copies of these figures may be made as follows: Dampen a sheet of printing-paper with a solution of tannin, and place it carefully on the figure after removing the magnet. Place on this a sheet of heavy blotting-paper, and apply a slight pressure. On lifting off the paper, most of the filings will adhere to it, and if brushed off when dry, will leave ink-like markings on the paper.

Excellent figures can be obtained by the use of blue-print paper. In that case the figures must be formed on glass.

II. Static Electricity.

81. Problem. — *To study the law of electrical action.*

Apparatus. — Two glass tubes, each about 2 cm. in diameter and 25 cm. long, two sticks of sealing-wax, a piece of silk, and a piece of flannel.

Method. — Electrify a glass tube by rubbing it with silk, and suspend it in a paper stirrup (Fig. 47). In like manner electrify a second glass tube, and bring it near the suspended one. Record the effect, and then bring near the suspended tube a stick of sealing-wax electrified by rubbing it with flannel. Now place in the stirrup an electrified stick of sealing-wax, and bring near it successively an electrified glass tube, and an electrified stick of sealing-wax. Record the effects observed in a table, and show wherein the law of electrical action is sustained.

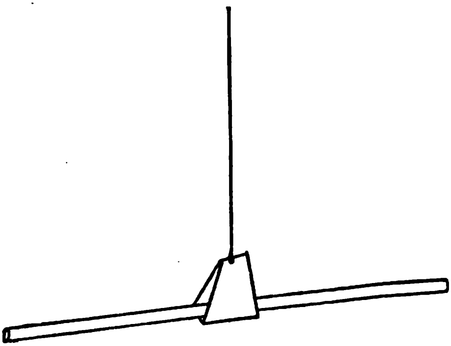
Fig. 47.

Remarks. — Neither prolonged rubbing nor hard pressure will intensify the electrification. The glass tube should be dry, and a few degrees warmer than the room. Lead glass gives the best effects, soda glass the poorest.

82. Problem. — *To charge an electroscope.*

Apparatus. — An **Electroscope** (Fig. 48) and a **Proof-plane** (Fig. 49). Directions for constructing an electroscope will be found in App. A. **6.** To make a proof-plane, cement a small metallic disk, as a bronze cent, to a glass tube or vulcanite rod.

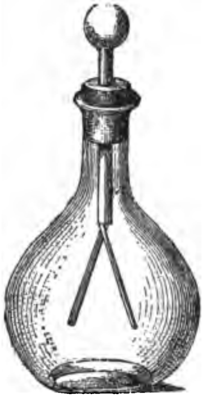

Fig. 48.

Method. — *First. By Conduction.* Excite a glass tube or stick of sealing-wax by friction. Slide the edge of the metal disk of the proof-plane along the surface, and then, without delay, touch it to the ball of the electroscope. Repeat the operation till a sufficient separation of the leaves is secured.

Second. By Induction. Hold a finger on the ball of the electroscope, and bring near the ball an electrified body, as a glass tube. Remove the finger *before* taking away the electrified body. The leaves of the electroscope will separate, and by the law of induction will be charged with the opposite kind of electrification to that of the body. The intensity of the electrical charge can be varied by varying the distance between the excited body and the ball of the electroscope during the act of charging.

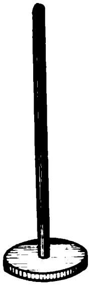

Fig. 49.

83. Problem. — *To ascertain the kind of electrification of a charged body.*

Apparatus. — An electroscope, a glass tube, a piece of silk, a stick of sealing-wax, and several substances to be tested.

Method. — Charge the electroscope by induction, using the electrified body to be tested for the purpose. Now bring near to the ball of the electroscope a glass tube electrified by friction with silk (+ E), and observe whether the leaves diverge farther or tend to collapse. In like manner bring up — E. The charge of the electroscope is of the same sign as that which increased the divergence, and hence that of the body under examination is of the opposite sign.

Remarks. — The *first movement* of the leaves as the electricity of known sign is brought near the electroscope must be recorded. If the glass of the electroscope becomes electrified, the indications of the instrument will be unreliable. Substances suitable for this experiment are glass, paper, fur, flannel, silk, wood, metal rods provided with glass or rubber handles, hard rubber, resin, rough glass, hot glass, wooden rod coated with shellac varnish, wooden rod coated with sulphur, cotton, paraffine, sealing-wax.

Form of Record. — Enter results like the following : —

NAME OF SUBSTANCE.	WITH WHAT RUBBED.	BEHAVIOR OF LEAVES OF ELECTROSCOPE WHEN + E WAS BROUGHT NEAR.	BEHAVIOR OF LEAVES OF ELECTROSCOPE WHEN — E WAS BROUGHT NEAR.	KIND OF ELECTRIFICATION OF BODY.
Vulcanite.	**Fur.**	**Diverg. is greater.**	**Diverg. is less.**	**Negative.**
etc.	etc.	etc.	etc.	etc.

III. Current Electricity.

a. LOCAL ACTION, CURRENT DIRECTION, POLARIZATION.

84. Problem. — *To show that local action is prevented by amalgamating the zinc.*

Apparatus. — A strip of sheet zinc and one of sheet copper, each 10 cm. by 3 cm., a glass tumbler three-fourths full of sulphuric acid diluted with 30 parts of water, and amalgamating fluid (APP. B. **10**).

Method. — Hold the strip of zinc vertically in the dilute acid, and observe closely the surface of the zinc for a minute or so. Also hold the copper strip in the acid without letting it touch the zinc, and watch its surface as well as that of the zinc for any changes in the previously observed action. Remove both strips, and let the liquid clear up. Now introduce both strips, but let their top ends touch. Examine closely the surface of each strip. Go over these steps at least twice, to ascertain if any of the phenomena were accidental.

Wash the zinc in water, and dip it for a few seconds in a tumbler of amalgamating fluid. Remove it, and wash thoroughly in water. If not uniformly bright, repeat the amalgamating operation.

Replace the zinc in the dilute acid, and repeat all the tests which were made with the unamalgamated zinc, comparing each observation with the corresponding one previously made.

Remarks. — Sheet zinc often has to be scoured before the dilute acid will act upon it. It may be amalgamated by rubbing mercury on its surface. If, during the experiment, the copper strip becomes amalgamated, heat it in a Bunsen flame. All jewelry should be removed from the hands before attempting this experiment. The gas given off during the experiment is impure hydrogen.

Form of Record. — Enter results under the following heads: —

CONDITIONS.	OBSERVATIONS.	INFERENCE.
....	....	....
....	....	....

85. Problem. — *To ascertain the action of an electric current on a mounted magnetic needle.*

Apparatus. — The voltaic cell, a stand for supporting the elements (Fig. 50), insulated copper wire No. 24, and a magnetic needle or pocket compass mounted in a grooved block (Fig. 51). The voltaic cell of ART. **84** will suffice for this experiment.

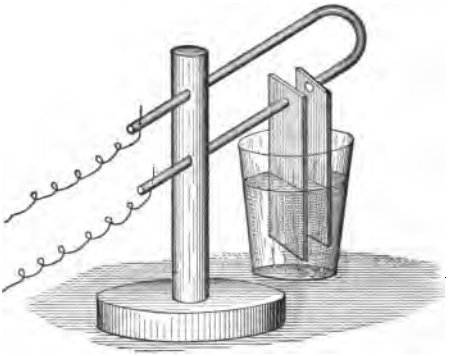

Fig. 50.

Method. — Remove the insulation from the ends of the wire, and connect these ends to the plates of the simple voltaic cell by inserting them in slots cut in the ends of the brass rods of the supporting stand. Hold the wire above the needle, parallel to it, and with the current passing from north to south. Record the effect on the needle. Hold the wire so that the current passes from south to north, and record the effect. Repeat the experiment with the wire below the needle. Now wind the wire once around the block, so that the plane of the loop of wire is vertical and passes through the needle, and record the effect. Try twice around, try three times, etc. Hold the right hand so that the index finger points out the direction of the current, and the extended thumb points out the direction in which the needle is deflected. Connect the galvanoscope just made to an electrical battery, and determine from the effect on the needle the direction of the current, and hence the positive pole of the battery. Give a rule for ascertaining the direction of an electric current.

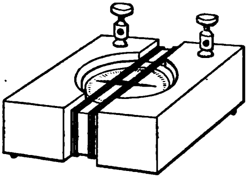

Fig. 51.

Remarks. — By winding the insulated wire several times around the block, and joining the ends to binding posts, as shown in Fig. 51, a simple and convenient galvanometer is obtained.

Form of Record. — Enter results under the following heads : —

CONDITIONS.	OBSERVATIONS.	INFERENCE.
....	....	....
....	....	....

86. **Problem.** — *Given strips of zinc, lead, iron, copper, tin, and carbon, to construct an electromotive series;* that is, to arrange them in a table such that if any two be used to make a voltaic cell, the current through the connecting wire will flow from the latter to the former.

Apparatus. — Similar to that of Art. **85.**

Method. — Attach two of the strips to the support, and by means of short copper wires connect the supporting rods to the galvanometer. Observe the deflection, and determine the direction of the current. Make as many different combinations as possible, and ascertain the direction of the current in each case. Tabulate the data, and construct the required series.

Remarks. — Be careful to place the galvanometer with the wires parallel to the needle. The series obtained is that which obtains when dilute sulphuric acid is used.

87. **Problem.** — *To study the effect of polarization.*

Apparatus. — Same as Art. **85.**

Method. — Place the galvanometer in circuit with the cell, and notice the amount of deflection. After a few seconds take the amount of deflection of the needle again. Now with a glass rod knock off the gas bubbles on the copper plate, and note the effect on the amount of deflection.

b. Electrical Measurements.

88. The Daniell Cell (Fig. 52), is undoubtedly the best type of cell for general laboratory purposes on account of its great constancy. It consists of a copper plate dipping in a solution of copper sulphate and a zinc prism dipping in a solution of zinc sulphate contained in a porous cup surrounded by the copper solution. When not in use the zinc should be removed, the zinc sulphate poured into a suitable vessel, and the porous cup submerged in a tank of water.

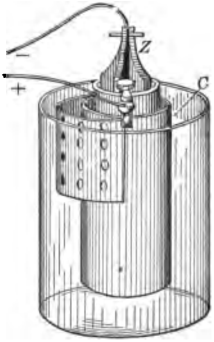

Fig. 52.

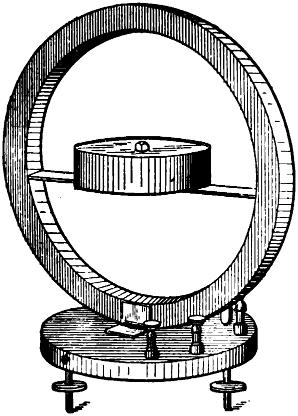

Fig. 53.

The Tangent Galvanometer (Fig. 53) should be provided with two or three coils so that a suitable deflection may be obtained in all cases. In adjusting it for use, set the coil or helix parallel to the needle, and level the instrument by means of the levelling screws so that both ends of the pointer read zero when no current is passing through the helix, and read as nearly alike as possible when deflected either way by the current. If the needle has a fibre suspension, it may happen that the fibre has become twisted, and the N-seeking pole of the magnet may not be toward the north. A bar magnet of known polarity should be used to remove all doubt. If the highest deflection of the galvanometer needle that can be secured lacks a few degrees of the amount required, and no other galvanometer is available, then support a bar magnet exactly over the needle, parallel to it, and at such a distance from it as to secure the required deflection. For aid in constructing a tangent galvanometer, consult App. A. **8**, **9**.

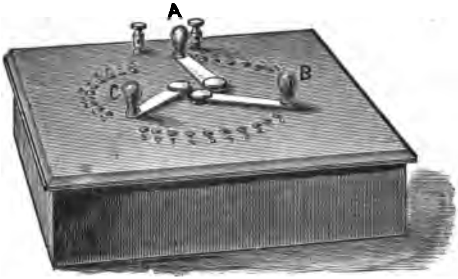

Fig. 54.

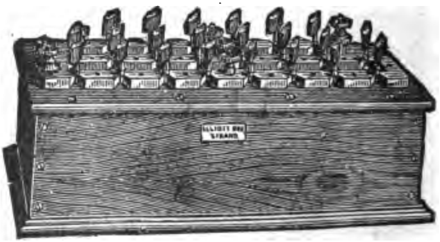

Fig. 55.

The Resistance-box usually consists of a collection of coils of insulated German-silver wire, the electrical resistance of each coil having some known relation to the standard unit of resistance, the Ohm. By means of movable arms (Fig. 54), or plugs (Fig. 55), as the case may be, any required resistance can be introduced in circuit with the battery. In resistance-boxes provided with switches, each switch must rest on a brass nailhead of the corresponding graduated arc. The value of the resistance introduced is obtained by adding together the readings adjacent to each switch. In the case of "plug" resistance-boxes, the plug is removed to introduce resistance,[1] and the total resistance introduced is the sum of the readings opposite the removed plugs.

The Commutator is a device for reversing the current. One of the simplest forms is the "two-hole" commutator (App. A. 7).

89. Problem. — *To measure the electrical resistance of a coil of wire by the method of substitution.*

Theory. — According to Ohm's law, the current furnished by an electrical generator varies inversely as the resistance of the circuit. Hence, to maintain a constant current, the resistance of the circuit must be kept constant. A constant current is made known by a galvanometer's maintaining a constant deflection when in circuit. Therefore, if a coil of wire and a galvanometer be in circuit with an electrical generator, and the coil be replaced by a conductor of known resistance with the effect of leaving unchanged the deflection of the galvanometer, the total resistance of the circuit must be the same as at first, and the known resistance introduced must be equal to that which it replaced.

Apparatus. — Daniell battery, galvanometer, telegraph key, resistance coils, wire for connections and **Double Connec-**

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[1] In some of the cheaper patterns the plugs are *inserted* instead of *removed* to introduce resistance.

tors (Fig. 56). The galvanometer selected should be one of high resistance if the coil to be measured has high resistance, and of low resistance if the coil has low resistance. In any case, when connected in circuit with the battery and coil, the deflection should be in the vicinity of 45°. The resistance coils should contain tenths of an ohm.

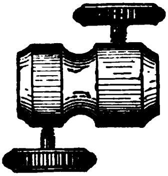

Fig. 56.

Method. — Form a circuit consisting of a constant battery, a galvanometer, a set of resistance coils, the conductor to be measured, and a telegraph key. Take the reading of the galvanometer when sufficient resistance has been introduced by means of the box to produce a deflection of about 45°. Drop the unknown conductor out of the circuit, connect the wires by a double connector, and introduce through the box sufficient resistance to produce the same reading of the galvanometer. The difference between the two readings of the resistance-box is the value of the unknown conductor. A number of trials should be made, employing resistances that differ somewhat, and the average obtained.

Remarks. — Be sure that all contacts are clean and well made. This method is worthless unless a constant battery is used. Why? A galvanometer deflection of about 45° is best, since the needle at that point is more sensitive to small changes in the resistance. In forming the circuit, place the galvanometer in front of you, near the edge of the table, the telegraph key to the left of the galvanometer, the resistance coils to the right, the battery at the middle of the table, and the conductor to be measured between the telegraph key and the battery. In dropping the unknown out of the circuit, *be careful not to disturb either the galvanometer or the battery.*

Form of Record. — Enter the results as follows : —

	1st R.	2d R.	x
1st trial,	14.3	14.9	.6
2d "	12.1	12.7	.6
3d "	17.7	18.4	.7
		Mean	.63 ohm.

90. Problem. — *To measure the electrical resistance of a coil of wire*[1] *by means of the Wheatstone bridge.*

Theory. — If four resistances are connected as shown in Fig. 57, and these are of such a value that no current flows through the galvanometer G, then

$$R'X = RR'' \text{ and } X = \frac{RR''}{R'}.$$

Apparatus. — A battery, set of resistance coils, Wheatstone bridge, wire for connections, telegraph key, and galvanometer. The battery need not be a constant one. It is preferable to have a Wheatstone bridge of the

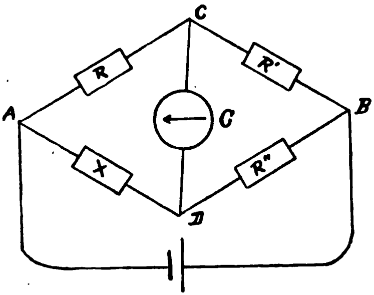

Fig. 57.

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[1] In the report, substitute the name of the article measured.

form shown in Fig. 58. For method of constructing it, see App. A. **10.** The galvanometer should be a very sensitive one, such as an astatic (Fig. 59), a d'Arsonval, or a Thomson reflecting.

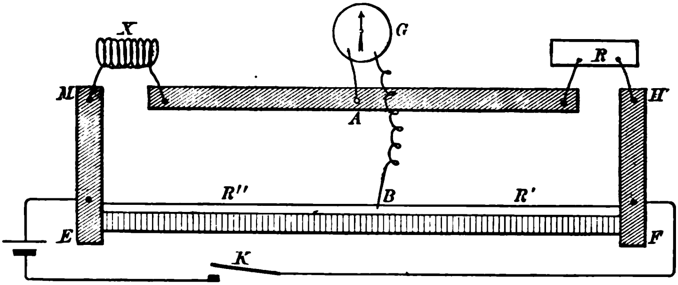

Fig. 58.

Method. — Connect the circuit as shown in Fig. 58. A telegraph key should be placed in the battery circuit, and the galvanometer should be located where the smallest motion of the needle can be seen. Introduce through *R* a resistance. Then close the battery circuit and slide *B* along the wire *EF* till a point is found at which the galvanometer is not affected; then *X* equals *R* multiplied by the ratio of *EB* to *BF*. Vary the conditions by giving different values to *R* successively.

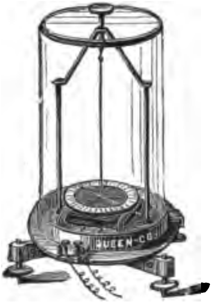

Fig. 59.

Remarks. — In practice it is best to find two positions for *B* on *EF*, at which the galvanometer deflections are in opposite directions. Then the point at which the galvanometer is not disturbed must be between these. When possible, it is best to give R a value somewhat near that of X, then the balance is secured near the centre of the scale, and errors will be less effective.

Form of Record. — Tabulate the data like the following: —

R.	R''.	R'.	X.
2	44.8	55.2	1.62
3	34.5	65.5	1.60
4	28.6	71.4	1.60
		Mean	1.61

91. Problem. — *To measure the resistance of a —— battery by the method of reduced deflection.*

Theory. — By Ohm's law $C = \frac{E}{R + r + g}$, in which R, r, and g represent the external resistance, the battery resistance, and the galvanometer resistance respectively. If the external resistance is changed to R', then $C' = \frac{E}{R' + r + g}$. Hence, $\frac{C}{C'} = \frac{R' + r + g}{R + r + g}$. If a is the deflection of the tangent galvanometer in circuit with the battery when the external resistance is R, and a' when the resistance is R', then $\frac{C}{C'} = \frac{\tan a}{\tan a'}$. Therefore, $\frac{R' + r + g}{R + r + g} = \frac{\tan a}{\tan a'}$, from which r can be obtained.

Apparatus. — Tangent galvanometer, No. 16 copper wire for connections, telegraph key, commutator, resistance coils, and battery.

Method. — Place the cell whose resistance is to be measured in circuit with a tangent galvanometer, commutator, telegraph key, and resistance coils. Use as little wire as possible in setting up the circuit, or else measure the resistance of the wire and add it to *R*. Select a galvanometer, such that when the resistance introduced by the coils is zero, the deflection of the needle is about 60°, and at the same time is sensitive to an increase of .1 ohm in the resistance. Adjust the galvanometer carefully to position, then introduce such a resistance, *R*, through the coils as to make the deflection, *a*, of the galvanometer about 55°. To get *a* as correctly as possible, read both ends of the needle, then reverse the current by means of the commutator, read both ends of the needle, and average the four readings for *a*. Now introduce a resistance of *R′* through the coils, such that the deflection, *a′*, of the galvanometer is about 35°. The value of *a′* should be obtained in the same manner as that used in obtaining *a*. Substitute the readings in the formula $\frac{R' + r + g}{R + r + g} = \frac{\tan a}{\tan a'}$, and solve for *r*. The tangents of the angles are obtained from Table XVIII. Several trials should be made with small variations in the resistances.

Remarks. — The galvanometer should be adjusted so that the two ends of the needle differ but slightly in their readings, and also that the readings on reversing the current agree quite closely with those obtained before reversing the current. High resistances would retard polarization, but are open to the objection that an extremely sensitive galvanometer will be needed in order to show the effect of a small resistance added by the battery. If not sensitive, changes of several ohms in the resistance may not appear to change perceptibly the reading of the pointer. With most batteries it will be necessary to secure the galvanometer readings with as little delay as possible, since they polarize rapidly when the circuit is closed.

Form of Record. — Enter the results as follows: —

	R.	Gal. Read.	a.	tan. a.	R′.	Gal. Read.	a'.	tan. a'.	g.	r.
1st trial . .	6.3	54.8 52.4 52.4 55.0	53.65	1.359	18.3	31.8 30.8 32.8 33.0	32.1	0.627	1.052	2.93
2d " . .	6.5	54.1 51.2 51.5 53.8	52.65	1.312	19.0	31.5 29.8 31.0 31.2	30.875	0.598	1.052	2.92
3d " . .	1.6	57.5 54.0 54.5 56.0	55.5	1.455	7.0	34.1 32.1 34.5 36.5	34.3	0.682	0.0515	3.11
									Mean, 2.99	

92. Problem. — *To measure the resistance of a —— battery by Mance's method.*

Theory. — If the battery be placed in one of the arms of the bridge, for example, in place of the X (Art. **90**), on closing the galvanometer circuit the needle is deflected. If R, R', and R'' be given such values, that on closing the battery circuit by means of the telegraph key, the deflection of the galvanometer remains unchanged, then $R'r = RR''$ and $r = \frac{RR''}{R'}$.

Apparatus. — A Wheatstone bridge, galvanometer (tangent), resistance coils, battery, key, and wires for connections.

Method. — Set up the circuit as in Art. **90**, except that the battery whose resistance is to be measured takes the place of X, and no battery is placed in the battery circuit, the key alone being placed there. The galvanometer, for ease in reading, should be placed between the bridge and the edge of the table. Now introduce through R a resistance equal to the probable resistance of the battery. If the galvanometer deflects beyond 45°, reduce its deflection either by supporting a bar magnet above the needle with its S-seeking pole over the N-seeking end of the needle, or by joining the posts of the galvanometer with a suitable shunt. Now find two positions for the slide key, such that on closing the battery circuit the galvanometer needle is moved in opposite directions. Then find the point between these two at which the deflection of the galvanometer is not changed on closing the battery key. Substitute the readings in the formula $r = \frac{RR''}{R'}$.

Remarks. — The resistance of batteries which polarize readily cannot be measured with any degree of accuracy by this method. In any case, the accurate measurement of the resistance of a battery is a difficult matter, since the resistance changes with any change in the external resistance of the circuit.

Form of Record. — Enter results as follows: —

R.	R'.	R''.	r.
2	52.5	47.5	1.81
1.8	47.5	52.5	1.99
2.3	51.5	48.5	2.17
		Mean	1.99

93. Problem. — *To compare the resistance of a single cell with that of two cells of the same size and kind when connected in parallel circuit, and also with that of the same cells connected in series.*

To connect cells in parallel circuit, join the positive poles together with a wire, making of them a single pole. In like manner join the negative poles.

To connect cells in series, join the positive pole of one to the negative pole of the next, thereby leaving the negative pole of the first cell and the positive pole of the last one to serve as the poles of the battery.

94. Problem. — *To test a galvanometer for the law of tangents.*

Theory. — By Ohm's law, $\frac{C}{C'} = \frac{R'}{R}$. By the law of tangents, $\frac{C}{C'} = \frac{\tan a}{\tan a'}$. Hence, $\frac{R'}{R} = \frac{\tan a}{\tan a'}$, and $R \tan a = R' \tan a'$, that is, $R \tan a =$ a constant quantity.

Apparatus. — Resistance coils, Daniell battery of known resistance, commutator, key, wires of known resistance for connections, and the galvanometer to be tested, the resistance being known.

Method. — Connect the apparatus in circuit, introduce resistance till the galvanometer reading is about 5°, read both ends of the needle, carefully estimating fractions, reverse the deflection, and read again. The value of a will be the average of these four readings. Then introduce less resistance till a

is about 10°. Continue increasing *a* by about 5° intervals till about 70° is reached. Multiply the *total resistance* of the circuit each time by the tangent of the angle of deflection. The degree of agreement among these products will indicate the closeness with which the galvanometer conforms to the tangent law.

To represent the results by a curve, lay off the resistances as ordinates, and the tangents as abscissæ, using cross-section paper for the purpose (**6**).

Form of Record. — Enter results as follows : —

R.	GAL. READINGS.		*a.*	*tan a.*	TOTAL *R.*	*R tan a.*
300	7.75	8.40	8.22	0.14445	307.9	44.476
	8.50	8.25				
180	12.75	13.40	13.22	0.23486	187.9	44.130
	13.50	13.25				
100	22.20	22.40	22.30	0.41013	107.9	44.253
	22.60	22.00				
60	32.70	33.40	32.95	0.64817	67.9	44.011
	33.20	32.50				
40	42.00	43.00	42.56	0.91824	47.9	43.985
	42.50	42.75				
20	56.00	57.50	56.75	1.52525	27.9	42.554
	57.00	56.50				

95. Problem. — *To find the reduction factor of a tangent galvanometer.*

Theory. — **The Reduction Factor** of a tangent galvanometer is a quantity such that when multiplied by the tangent of the angle of deflection it gives the strength of the current in amperes. The law of the tangent galvanometer is $C = K \tan a$,

K being the reduction factor. Hence, $K = \frac{C}{tan\ a}$. By Ohm's law, $C = \frac{E}{R + r + g}$. Therefore, $K = \frac{E}{(R + r + g)\ tan\ a}$. If a Daniell cell is used, an approximate value for K can be obtained by assuming $E = 1.08$ volts.

Apparatus. — A tangent galvanometer, commutator, resistance coils, Daniell battery of known resistance, wires of known resistance for connections, and a key.

Method. — Connect in circuit a Daniell cell, having first found its internal resistance, a commutator, resistance coils, tangent galvanometer, and key. Introduce a resistance R, so as to obtain a deflection of the galvanometer between 25° and 60°. In obtaining a, read both ends of the pointer, reverse, and average the four readings. Substitute in the formula $K = \frac{E}{(R + r + g)\ tan\ a}$, assuming $E = 1.08$. If any value of $tan\ a$ for this galvanometer be multiplied by this value of K, the product will be approximately the current in amperes.

Remarks. — The value of R should include the resistance of the wires with which the connections are made.

96. Problem. — *To measure the electromotive-force of a —— battery by the method of constant resistance.*

Theory. — When the standard cell is in circuit with the resistance coils and the tangent galvanometer, $C = \frac{E}{R + r + g}$.

When the cell whose E.M.F. is required is substituted for the standard, $C' = \frac{E'}{R' + r' + g}$. Hence, $\frac{C}{C'} = \frac{R' + r' + g}{R + r + g} \cdot \frac{E}{E'}$. According to the law of tangents, $\frac{C}{C'} = \frac{\tan a}{\tan a'}$. Therefore, $\frac{R' + r' + g}{R + r + g} \cdot \frac{E}{E'} = \frac{\tan a}{\tan a'}$. Now, if R' be so taken in obtaining a', that $R' + r' + g = R + r + g$, this formula reduces to $\frac{E}{E} = \frac{\tan a}{\tan a'}$, and $E' = E \cdot \frac{\tan a'}{\tan a}$.

Apparatus. — A Daniell cell of known resistance, a cell whose E. M. F. is required, also of known resistance, a tangent galvanometer, commutator, key, resistance coils, and wires for connections.

Method. — Connect the apparatus in circuit with the standard cell, and adjust R till the deflection of the galvanometer is between 25° and 60°. The galvanometer should be so chosen that R may be large in order to retard polarization. The angle of deflection, a, should be read with great care, averaging the readings of both ends of the needle with those when the current is reversed. Now substitute the battery whose E. M. F. is required, adjusting the resistance through the resistance coils so that $R' = R + r - r'$, and obtain a'. Assuming $E = 1.08$ volts, compute E' by the formula $E' = E \cdot \frac{\tan a'}{\tan a}$.

Remarks. — The resistance of both cells should be measured immediately preceding the measurement of E. M. F. If a galvanometer of large resistance, say, several hundred ohms, be used, the resistance coils may be omitted from the circuit, and the resistance of the batteries, being small relatively, may be neglected without sensible error.

Form of Record. — Enter results as follows: —

R	R'	R''	r	R	R'	R''	r'		
3	49.9	50.1	3.01	3	70	30	1.28		
R	r	g	TOTAL R	a		R'	r'	a'	E'
4	3.01	2.25	9.26	56.0 58.0 54.5 56.2	56.17	5.7	1.28	57.0 56.2 55.4 54.2 55.7	1.00
6	3.01	2.25	11.26	53.8 50.6 51.8 52.0	52.05	7.7	1.28	53.6 51.0 51.4 49.4 51.3	1.05
7	3.01	2.25	12.26	51.2 51.5 50.0 49.8	50.62	8.7	1.28	49.8 47.0 52.2 48.2 49.3	1.03

97. Problem. — *To measure the electromotive-force of a —— battery by the Wheatstone method.*

Theory. — If a standard cell is in circuit with a galvanometer, key, and resistance coils, then $C = \dfrac{E}{R + r + g}$. If R is increased by R' so as to reduce a an observed number of degrees, say, 10°, then $C' = \dfrac{E}{R + R' + r + g}$. If the cell whose E. M. F. is required is introduced in place of the standard cell, and the resistance through the coils is changed to R'', so that the galvanometer reads the same as in the first case, then $C = \dfrac{E'}{R'' + r' + g}$. If R'' is increased by R''' so as to reduce a the same number of degrees as before, then $C' =$

$\frac{E'}{R''+R'''+r'+g}$. Therefore, $\frac{E}{R+r+g}=\frac{E'}{R''+r+g}$, and $\frac{E}{R+R'+r+g}=\frac{E'}{R''+R'''+r'+g}$. Invert the members of these equations, and then subtract one equation from the other; we have $\frac{R'}{E}=\frac{R'''}{E'}$, that is, the E. M. F. of two cells are to each other as the resistances which produce equal diminutions of current strength.

Apparatus. — A Daniell cell, cell of unknown E. M. F., key, galvanometer, wires for connections, and resistance coils.

Method. — Connect the apparatus in circuit with the weaker of the two cells, the standard and the unknown. When a resistance, R, is used, record the deflection a of the galvanometer. Then introduce additional resistance, R', to reduce the a any convenient number of degrees, as 10°. The galvanometer should be selected so as to give a deflection in the vicinity of 45°, and at the same time permit a large resistance in the circuit to retard polarization. Now exchange batteries, and introduce such a resistance, as R'', as to produce the same deflection, a. Then introduce additional resistance, R''', to reduce a the same number of degrees as before. Compute E' from the formula $E'=E\cdot\frac{R'''}{R'}$.

Form of Record. — Enter results as follows: —

R.	$R+R'$.	R'.	a.	R''.	$R''+R'''$.	R'''.	E'.
5.3	9.4	4.1	45°	5.5	9.1	3.6	.95
7.4	12.6	5.2	40°	6.6	10.8	4.2	.87
5.5	9.7	4.2	45°	5.3	8.4	3.1	.80
						Mean	.87

98. Problem. — *To measure the E.M.F. of a cell and compare it with that of two cells of the same kind when joined in multiple arc. Also to compare it with that of two when joined in series.*

The method of either Arts. **96** or **97** may be employed in solving this problem.

c. Action of Currents and Magnets Currents.

99. Problem. — *To investigate the behavior toward each other of two conductors carrying electric currents.*

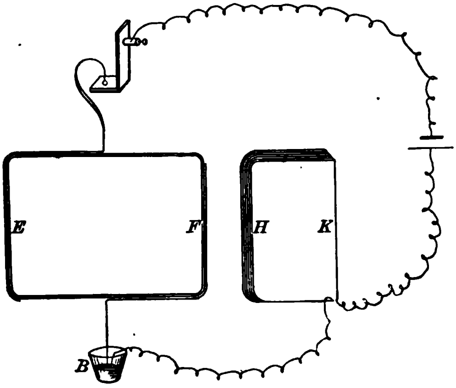

Fig. 60.

Apparatus. — Construct a rectangular frame, 25 cm. square, out of insulated copper wire, No. 20, by winding about four layers around the edge of a square board. Slip the wire off the board, and tie the parts together in a number of places with fine cord. Bend one end of the wire into a hook form (Fig. 60), the other end to be left straight, extending out from the other side. Bend a narrow strip of brass into a J-form, giving the hooked part a spoon-shape, so that it will hold a small globule of mercury. Support the strip in a burette-holder, and hang the rectangle from it with the straight end dipping into a vessel of mercury. Adjust the shape of the hooked part of the wire so that the upper and the lower sides of the rectangle are horizontal, the frame keeping any position given it, and turning on application of the slightest force. The supporting point of the frame should be conical, good contact being secured by a globule of mercury. Wind four or five layers of insulated wire around the edge of a board, *HK*, 20 cm. by 10 cm.

Construct a **Solenoid** (Fig. 61) by winding some No. 16 insulated wire into a close spiral, arranging it for suspension in the same manner as in the case of the wire rectangle. The solenoid should have a diameter of about 4 cm. and a length of 15 cm.

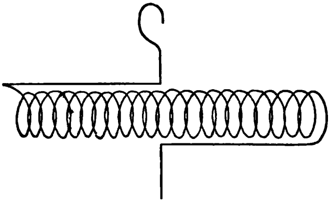

Fig. 61.

Method. — Place the wire rectangle in circuit with a battery of two or three cells, by connecting one pole to the strip, and the other to the vessel of mercury. If the plane of the rectangle be situated north and south, the rectangle, if carefully mounted, will turn till its plane lies east and west. Reverse the current and record the effect. Trace the current through the rectangle and record its direction.

Place in the same battery circuit the coil *HK*, and support it so that the current through it is parallel to that through *F* and near to it. Record the effect when the direction of the currents through *F* and *H* is down. When the direction in both is up. When down in one and up in the other. Frame a law expressing the results.

Hold *HK* within *EF* so that the edge *H* makes an angle with the lower side of *EF*. Frame a law expressing the results.

Remove *HK* from the circuit, and double part of the wire of the circuit on itself as shown in Fig. 62, and hold it parallel to one of the vertical sides of the wire rectangle. Compare the effect with that of a wire not doubled on itself.

Substitute for the simple loop a spiral with the return wire passing in a straight line through it (Fig. 62). If the effect is the same as that of a simple loop, then a sinuous current must equal the straight current.

Place a bar magnet beneath the suspended rectangle and note the effect. Turn the magnet end for end, and again note the effect.

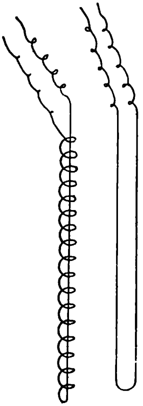

Fig. 62.

Suspend the solenoid in place of the wire frame, close the circuit, and hold a bar magnet near one of its ends. Ascertain the effect of reversing the current. Trace the current through the solenoid. In what direction is it moving in the N-seeking end? Place a few iron wires within the coil and note the effect.

Place the rectangle *HK* in circuit with the solenoid. Hold one edge of *HK* above the solenoid and parallel to its axis. Compare the direction of the current in *H* with that in the solenoid, on the solenoid's coming to rest. What law is illustrated?

Remarks. — The magnetic properties of a solenoid or helix are very instructively exhibited by obtaining its magnetic field. This may be done by placing the solenoid in a rectangular opening cut in a sheet of cardboard, with the axis in the plane of the cardboard. If, in cutting the rectangle, one end is not cut across, and the strip is passed through the axis of the helix, it would be better. Then sift iron filings around the coil, while a current is passing through it; a field resembling that given by a magnet will be obtained. Now fill the opening through the coil below the cardboard with iron wires, cut the length of the coil, and repeat the experiment. Compare the lines of magnetic force with those obtained before using the wire coil.

Form of Record. — Record briefly and clearly the result of each experiment, and point out in the discussion the laws and truths established.

d. CURRENT INDUCTION.

100. Problem. — *To investigate the laws of magneto-electric induction.*

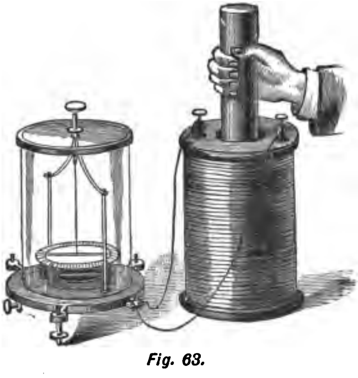

Fig. 63.

Apparatus. — A sensitive galvanometer, a hollow spool of insulated wire (Fig. 63), a strong bar magnet, and a battery.

Method. — Connect the hollow helix by long wires to the galvanometer. Introduce suddenly into the helix the N-seeking pole of a strong bar magnet. Record the direction of the deflection of the needle. Place a battery in circuit with the helix and galvanometer so as to deflect the needle in the same direction as when the N-seeking pole of the magnet was inserted in the helix. Trace the direction of the current through the helix. Compare the direction of the induced current with that of the hands of a watch. Remove the battery, and ascertain if there is any current when the magnet is stationary within the helix. Study the effects attending a slow introduction of the magnet. Try the S-seeking pole. Find the effect of suddenly removing the magnet. Try a stronger magnet made by placing two together with their like poles adjacent. Express as laws the conclusions reached.

Remarks. — If the direction of the winding of the helix cannot be determined by an inspection of the spool, connect the battery in circuit exactly as was done in the experiment, then with a compass needle ascertain the polarity of the coil. By grasping the coil with the right hand so that the extended thumb points toward the N-seeking pole, the fingers will extend around the coil in the direction in which the battery current is moving, and hence in the direction of the induced current when the N-seeking pole of the bar magnet was inserted.

101. Problem. — *To investigate the laws of current induction.*

Apparatus. — Two helices of wire, one of which can be inserted in the opening in the other (Fig. 64), a battery, and a sensitive galvanometer.

Method. — Connect the smaller helix in circuit with a battery. Connect the larger helix to the galvanometer. Insert the smaller helix quickly within the larger one, and note the effect on the galvanometer. Find as in ART. **100** the direction of the current in the larger helix. Ascertain the effect of removing the helix. Place the smaller helix within the larger one, and try the effect of opening and closing the circuit. Insert a set of resistance coils in the battery circuit, and ascertain if there is any induction produced on weakening or strengthening the battery current by changing the resistance. Within the smaller helix place a bundle of fine iron wire and repeat all the tests, comparing the results with those previously obtained. What laws express the results of the experiment? In the discussion, compare these laws with those of magneto-electric induction, and point out their similarity.

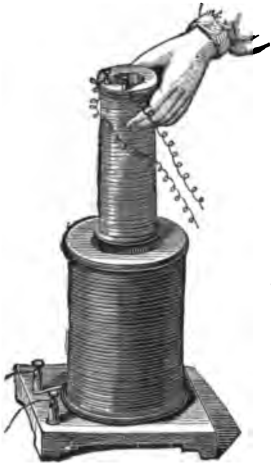

Fig. 64.

CHAPTER VII.

SOUND.

I. Re-enforcement of Sound

102. Problem.—*To find what lengths of air-columns will re-enforce the sound of a tuning-fork.*

Apparatus.—Eight glass tubes, each 2.5 cm. in diameter and of a length to re-enforce, when closed at one end, a certain tuning-fork, say A′, at the temperature of the room; seven pieces of rubber tubing 2.5 cm. in diameter and 3 cm. long to serve as connectors for these glass tubes; a tuning-fork of the same pitch as that used in determining the length of the glass tubes.

To obtain the length of the glass tube, hold it vertically in a vessel of water, set the fork in vibration, and hold its prongs over the open end of the tube; then move the tube till the re-enforcement is strongest, and mark the position of the water. Cut the tube off at the place marked (App. B. **1**).

Method.—Cement a paper disk over one end of one of the glass tubes, thereby making what is known as a "closed" tube. Now connect to the open end other tubes, thereby preparing closed tubes having lengths 2, 3, 4, etc., times that of the single tube. Find by trial which of these multiples re-enforce the sound of the fork.

In like manner connect the tubes without closing one end, thus forming "open" tubes, and find if a re-enforcement of the sound is possible with any of them. If the length of the shortest open tube which re-enforces the sound is considered as the unit, find which multiples of it will re-enforce the sound.

Remarks. — A small tuning-fork may be set in vibration by striking one of its prongs against a piece of soft wood. Large forks may be set in vibration by striking the face of one of the prongs near the free end with a mallet made by attaching a handle to a rubber pencil eraser. The same position of the prongs over the mouth of the tube must be maintained throughout the whole work.

103. Problem. — *To find what correction must be made for diameter in the length of a cylindrical resonating air-column.*

Apparatus. — A tuning-fork whose vibration-rate is accurately known, a set of three glass cylinders of diameters from 2 cm. to 5 cm. and 40 cm. long, a pair of inside calipers, a thermometer, a linear scale, and a deep jar of water.

Method. — Measure the inside diameter of each tube. Support each one successively in a vertical position with the lower end dipping in the jar of water. Hold the prongs of the vibrating fork over the open end of the tube, then raise or lower the tube till the shortest length of air-column is found which gives the loudest resonance. Measure the length of the air-column and the temperature of the air. Make a number of trials of each tube. If t represent the temperature, and v the velocity of sound in the air, then $v = 332 + .6\,t$. If n is the vibration-rate of the fork, and l the wave-length, then $l = \frac{v}{n}$, and $\frac{l}{4}$ = the length of the shortest resonating column. The length obtained by the experiment will be shorter than that given by computation. The difference divided by the diameter of the corresponding tube will be the correction required, that is, will be that part of the diameter of a cylindrical resonator to be added to the observed length of the resonating column to give the true length. This quantity, decimally expressed, should be obtained for each tube of the set, and the average obtained for a final result.

Remarks. — That the diameter does affect the length of the resonating column is shown by the difference between the length of the computed air-column and the observed one, increasing with the diameter.

Form of Record. — The results may be tabulated as follows :—

N.	DIAM.	LENGTH OF AIR-COL.	TEMP.	VEL. OF SOUND.	THEORETICAL LENGTH OF AIR-COL.	DIFFERENCE.	RATIO.
256	2.0 cm.	32.54 cm.	19°	343.4 m.	33.54 cm.	0.86	.43
		32.70 cm.					
		32.80 cm.					
		32.68 cm.					
256	4.0 cm.	32.06 cm.	19°	343.4 m.	33.54 cm.	1.62	.40
		31.50 cm.					
		32.20 cm.					
		31.92 cm.					
256	4.5 cm.	31.90 cm.	19°	343.4 m.	33.54 cm.	1.81	.40
		31.70 cm.					
		31.60 cm.					
		31.73 cm.				Mean	.41

II. Velocity of Sound.

104. Problem. — *To determine the velocity of sound in air.*

Theory. — If a cylindrical column of air have a suitable length, it will re-enforce the sound of a tuning-fork. The shortest effective column is one-fourth of a wave-length. Resonance can also be secured by a column three, five, seven, etc., times longer than the minimum column. The column shortens on increasing the diameter, the theoretical length being greater than the actual by about two-fifths of its diameter. If a is the length of the shortest resonating air-column, d its diameter, l the wave-length, n the number of vibrations per second of the fork, and v the velocity of sound, then $l = 4\,(a + \frac{2}{5}\,d)$ and $v = ln = 4n\,(a + \frac{2}{5}\,d)$.

Apparatus. — A tuning-fork making between 200 and 400 vibrations per second, the exact number being known, a thermometer, a glass tube about 100 cm. long and 3 cm. diameter, closed at one end with a cork, through which passes a small tube, a piece of rubber tubing about one metre long, a funnel, and wooden clamps.

Method. — Connect the funnel and the glass tube inserted in the cork by means of the rubber tube. Support the funnel on the table, and the large glass tube on the floor with the open end near the edge of the table. Clamp the fork with the ends of its prongs over the open end of the glass tube. Pour water into the tube through the funnel. Strike the fork with a mallet made out of a common rubber pencil eraser. While the fork is sounding, vary the length of the air-column in the tube by raising or lowering the funnel, till a strong re-enforcement of the sound of the fork is secured. Measure the length of this resonating air-column, the diameter of the tube, and the temperature of the air within it. If the tube is long enough, two or three different lengths of air-columns will be found to give a strong re-enforcement. Several trials should be made for each length, and the average obtained. Find the value of the shortest resonating air-column in each case by dividing by the number of the multiple. Correct this value in each case by two-fifths of the diameter of the tube, and compute the velocity, as shown under "Theory."

Form of Record. — Tabulate the results as follows : —

	Vib. No.	Length of Air-Col.	Length of Air-Col.	Diam. of Tube.	Temp.
1st trial	....	....	....	....	....
2d "	....	....	....	....	....
	etc.	etc.	etc.	etc.	etc.
	Mean	....	....	....	....
	$a =$	....	....		
	$l =$	....	....		
	$v =$	....	....		
	Theoretical $v =$	....			
	Error =	....	....		

105. Problem. — *To determine the velocity of sound in glass.*

Theory. — If a glass tube is clamped at the middle, and one-half of it is stroked horizontally with a wet cloth, it emits a sound whose wave-length is twice the length of the tube.

If the vibration of this tube is communicated to the air within a second tube closed at one end, it sets up a succession of waves which interfere on reflection from the closed end-producing nodes. The distance between two successive nodes will be half a wave-length in air for the sound emitted by the glass tube. If d is the length of the glass tube, then $2d$ is the wave-length of the wave in the glass. If s is the distance between two nodes, then $2s$ is the wave-length of the same sound in air. Hence, $2d \div 2s$ or $d \div s$ will be the number of times that the sound travels in glass faster than it does in air. Experiment shows that sound travels 332 metres per second in air at 0° C., and changes .6 m. per second for 1° C. change of temperature. Let $v =$ velocity of sound in air at 0° C. Then $v = 332 + .6t$. Let $V =$ velocity of sound in glass. Then

$$V = \frac{d}{s} v = \frac{d}{s} (332 + .6t).$$

Apparatus. — A glass tube about 1 m. long and 4 cm. in diameter, closed at one end with a cork, a heavy glass tube about 1.5 m. long and 1.5 cm. in diameter with a thin cork piston cemented to one end, fine cork-dust made by filing a cork, a damp cotton cloth, a clamping device consisting of two pieces of wood having the shape shown at F. (Fig. 65), and an iron clamp. The thickness of the wooden pieces should be such that the tube is in the axis of AC as it rests on the table; the hole through them being just large enough to hold the tube without crushing.

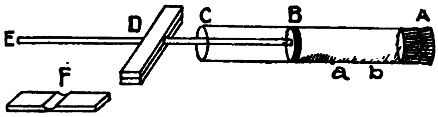

Fig. 65.

Method. — Clamp the tube EB at its centre, with the piston B within the larger tube. This piston must not press against the walls of the tube. Distribute evenly a little cork-dust between A and B. Now excite longitudinal vibrations in BE by gently stroking it toward E with a damp cotton cloth, *being careful not to spring the tube out of line for fear of breaking it.* These vibrations will be communicated by the piston B to the air between A and B and disturb the powder. By moving AC, a position for B can be readily found at which the agitation of the powder is greatest, the powder being thrown into clearly marked heaps of uniform length subdivided into parallel ridges. When B is correctly placed, there is a node at B and also one at A, and the heaps of powder at the ends will be of the same length as the others. Measure the distance between the face of the piston and that of the cork, divide this by the number of these heaps, and s, the length of one heap, is obtained. Measure d, the length of the glass tube giving the vibrations, and also the temperature of the air at the place. Substitute these values in the formula

$$V = \frac{d}{s}(332 + .6\,t).$$

Remarks. — The velocity of sound in wooden or metallic rods may be measured in like manner. To set such rods in vibration, use a piece of soft leather dusted over with powdered rosin.

Form of Record. — Tabulate the results so that averages may be readily obtained for use in the final computation.

III. Reflection of Sound.

106. Problem. — *To test the law for reflection of sound-waves.*

Apparatus. — Two tin tubes, each 1.5 m. long and 5 cm. in diameter, a semicircular protractor of cardboard having a radius of at least 30 cm., a plate of glass, and a watch.

Method. — Place the tubes on the protractor, forming a V (Fig. 66), with the zero of the scale midway between the tubes. Support the plate of glass across the ends of the tubes at the V, in a plane normal to the zero line of the protractor. Suspend a watch close to the outer end of one of the tubes, and listen for the sound of the ticking at the free end of the other tube. Try the effect of removing the glass plate. Try the effect of having one tube considerably nearer the zero line of the protractor than the other one is. Make many trials, tabulate the results, and draw suitable inferences from the data.

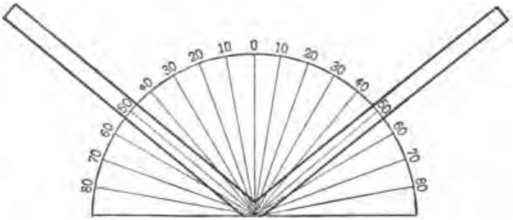

Fig. 66.

Remarks. — The room must be quiet. The ticking can probably be heard in all positions of the tubes, but in some positions the sound will be considerably louder than in others.

IV. Pitch of Sounds.

107. Problem. — *To find the vibration-number of a tuning-fork by the method of interference of sounds.*

Apparatus. — Two large T-tubes, a funnel, rubber tubing, and a tuning-fork.

Method. — Connect the tubes as shown in Fig. 67. Join the funnel to the stem of one T-tube and a piece of rubber tubing to the other. Hold the vibrating fork at *A*. It is evident that the waves divide at *B*, traverse each branch, and unite at *K*, reaching the ear through *H*. If the tube *CDE* is half a wave-length longer than *F*, the waves will meet in opposite phases at *K*, and no sound at *H* will be heard. Similar effects will follow if the difference is $\frac{3}{2}$, $\frac{5}{2}$, $\frac{7}{2}$, etc., of a wave-length. Hence, find by trial the length of the least difference between *CDE* and *F* when the sound is destroyed; twice this will be the wave-length. Compute the velocity of sound in air as directed in Art. **105**, and divide it by the wave-length, the quotient will be the vibration-number.

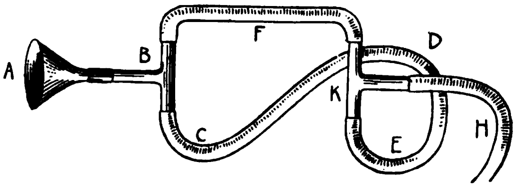

Fig. 67.

Remarks. — It may be impossible to extinguish the sound completely on account of the conductivity of the tubing. In

Apparatus. — A pine bar 2 m. long, 3 cm. wide and 6 mm. thick, a second bar of the same length and width and 12 mm. thick, a third bar of the same length and thickness as the first bar and 6 cm. wide, an iron clamp, and a watch marking seconds.

Method. — Clamp these bars successively at one end over the edge of a table with an iron clamp, set each in vibration, and count the number of vibrations made in some convenient period of time. Clamp the first bar so that the part which vibrates is one-half of that which was used at first. What effect does width, thickness, and length have on the vibration-rate? Repeat the trials several times, and tabulate the results.

Remarks. — If the rate of vibration is quite rapid, more accurate results can be obtained by counting the vibrations by tens.

111. Problem. — *To investigate the laws of vibrating strings.*

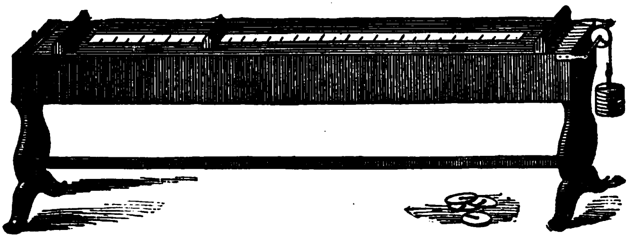

Fig. 69.

Apparatus. — A **Sonometer** (Fig. 69), a **Siren** (Fig. 68), giving at least the major chord, or a set of tuning-forks sounding the major chord, and a micrometer caliper (**14**). The sonometer is a wooden box about 150 cm. long, made of pine, free from pitch, straight-grained, and about 1 cm. thick, except the top, which may be 5 mm. thick. The ends or head-pieces are made of thoroughly seasoned hard wood. Near each end there is glued to the top a triangular piece of hard wood, about 3 cm. deep, to serve as a bridge. The distance between the bridges is 120 cm. Piano wires are stretched across these bridges, the ends being fastened to the head-pieces. To regulate and measure the tension, various devices are employed. In some instruments the strings run over pulleys, and are stretched by weights of known value (Fig. 69). Other instruments have stout steel spiral springs attached to one of the end pieces. An index fastened to the spring moves over a scale, giving the tension. The Ritchie sonometer uses a lever; the absolute tension is not obtained, but the relative tension of two strings is ascertained by measuring the arms of the lever. Where the tension is not varied by weights, there are piano posts in the head-piece opposite the tension-measuring device for varying the tension.

Method. — Stretch a wire on the sonometer, and then tune it by the movable bridge till the pitch of the sound is that given by the inner row of holes of the siren, or by the lowest of the set of four forks. Now shorten the wire by means of the movable bridge, till the pitch of its sound is that given by the second row or fork; then till it is that of the third row or fork; and finally till it is that of the fourth row or highest fork. The length of wire should be recorded in each case. Compare the ratio of these lengths with those of the siren-sounds or fork-sounds.

Stretch two steel wires of different diameters, giving them the same tension. Shorten with a movable bridge the one of lower pitch till it sounds in unison with the higher. Find the ratio of the diameter of the larger wire to the smaller one, and compare it with that of the length of the longer wire to that of the shorter one. If equal, then the pitch must vary inversely as the diameter, since the larger wire had to be shortened to bring its pitch up to that of the smaller.

Stretch two steel wires of the same diameter, giving them different tensions. By means of the movable bridge shorten the wire of lower pitch till it sounds in unison with the higher. Compare the ratio of the tensions with that of the lengths, and thereby ascertain the effect of tension on pitch.

Stretch a brass and a steel wire of the same diameter, giving them equal tensions. By means of the movable bridge under the wire of lower pitch, shorten it till the wires sound in unison. Compare the ratio of the lengths of the wires with that of the densities.

Remarks. — Be careful not to screw the tuning-posts too far into the head-piece. Every time a change is made in the wires, the posts should be turned back to their position at the beginning.

Form of Record. — Enter results as follows: —

1st	Length of wires, giving major chord .	....	....	....	....
	Ratio of these lengths to shortest . .	....	....	....	....
	Ratio of tones comprising major chord,	....	....	....	....
2d	Diameters of wires		....	....	
	Lengths of wires when in unison . .		....	....	
	Ratio of diameters of wires		....		
	Ratio of lengths of wires when in unison		....		
3d	Tensions of wires.		....	....	
	Square root of ratio of tension of wires,		....		
	Ratio of lengths of wires		....		
4th	Ratio of densities of wires		....		
	Ratio of lengths of wires		....		

VI. Optical Study of Sounds.

112. Problem. — *To analyze sounds by means of Koenig's manometric flame.*

Apparatus. — A rotating mirror and a manometric capsule provided with a speaking-tube. A fairly efficient apparatus may be prepared as follows: Cut out of a board 2.5 cm. thick, a strip 4 cm. wide and 25 cm. long. Near one end bore a hole 2.5 cm. in diameter, half-way through it. Cut a second piece of the same width and 5 cm. long, and bore into it a similar hole. Screw these two pieces together so that the two holes face each other, separating them, however, by a membrane of gold-beater's skin, thus forming a box divided into two parts by this elastic partition. Fasten the long strip to a suitable board for a support (Fig. 70). Bore into the box three holes, two in the face, *B*, and one in the other. Into the latter cement a metal tube, *E*, about 2 cm. in diameter, for the purpose of attaching a short rubber tube leading to a funnel-shaped mouthpiece. In the other holes cement a jet-tube, *D*, and a straight tube for making connection with the gas supply. For a mirror, cut a wooden cube, 10 cm. on each edge, as *M*. Insert in the centres of two opposite faces stout wires, as *K* and *H*. Tie on the lateral faces squares of looking-glass.

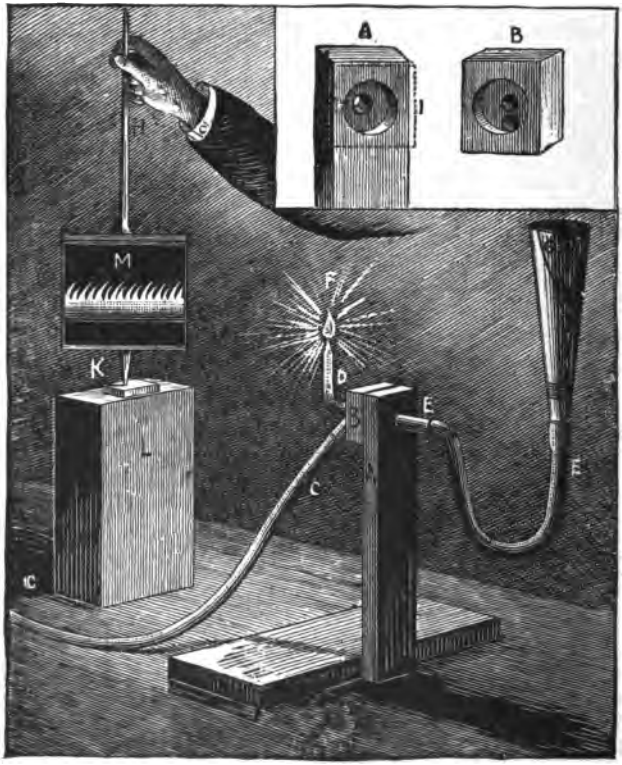

Fig. 70.

Method. — Admit illuminating gas to the capsule, and light it as it escapes through the jet-tube. Adjust the gas supply so that the flame is about 1.5 cm. long. Rotate the mirror in front of the flame, and mark the appearance of the flame in the mirror. Sing in the funnel mouthpiece, *oo* in p*oo*l. Ascertain the effect of changing the pitch. Sing the vowel *o* in n*o*te, giving it successively the pitch of the eight notes in the octave from C to C′. Sing successively the vowel *a* in fl*a*me, *a* in f*a*ther, *a* in *a*s, keeping the pitch the same. The sounds produced each time should be prolonged and characterized by considerable intensity.

Form of Record. — Diagram accurately each flame picture, marking carefully every indentation. In discussing these figures, point out the presence and absence of overtones as far as possible. Observe whether raising the pitch affected the presence of overtones. The record should show whether the tones changed in quality with an increase of pitch.

CHAPTER VIII.

LIGHT.

I. Images Through Small Apertures.

113. Problem.—*To ascertain how images are formed by small apertures, and what conditions govern their size, brightness, and definition.*

Apparatus.—A lamp, two screens, and a sheet of cardboard. The screens should be of thin pine board, about 30 cm. square, and fitted to a base. One of the screens should have an aperture at its centre about 5 cm. square. The sheet of cardboard should be rolled into a cylinder of sufficient diameter to encircle the lamp. A circular aperture, 2 mm. in diameter, should be cut in it opposite the lowest point of the lamp-flame, as it encircles the lamp.

Method.—This experiment must be conducted in a darkened room. Tack a piece of heavy paper over the aperture in the screen. Cut a hole about 4 mm. square in this paper. Place the lamp, the screen with aperture, and the screen without aperture in the order named, and about 15 cm. apart. Place the paper cylinder around the lamp so that the light, passing through the small aperture, is incident on the first screen, forming an image of the flame. Adjust the apparatus so that some of the light passes through the first screen to the second one. By observing what part of the image of the flame is over the aperture in the first screen, it will be known from what part of the flame the light comes that produces the figure on the second screen. With a pencil trace the outline of this figure seen on the second screen. Now adjust the cylinder about the lamp, so as to take light successively from a series of points in the border of the flame, tracing on the second screen the figure obtained each time, being careful not to change the positions of the lamp and the screens. Connect with a pencil line the centres of these figures. Now remove the cylinder, and observe the figure obtained, comparing it with the pencil sketch.

Make three apertures in the first screen, one square, one round, and one triangular, of about equal area. Compare the images formed on the second screen. Try apertures of various sizes. Try as large a one as possible. Vary the distance between the screens; also between the lamp and the screen.

Form of Record. — Describe briefly each change made in the conditions, and accompany it by a clear description of the image obtained. Copy the figure obtained on the screen when the lamp was surrounded by the cylinder. In the discussion show the following, referring to your results to establish your conclusions: 1st. What is the composition of images produced by small apertures? 2d. What effect does the shape of the aperture have on the image? Why? 3d. On what does the size of the image depend? 4th. On what does the brightness of the image depend? 5th. On what does the definition of the image depend? 6th. Under what conditions will the aperture fail to give an image of the object?

114. Problem. — *To ascertain why an image of every object is not seen imprinted on every other object, in accordance* *with the principle governing the formation of images through small apertures, any point in space being considered as such an aperture.*

Apparatus. — Same as Art. **113**.

Method. — Tack a piece of writing-paper over the aperture in the screen, and place the lamp and the two screens as in Art. **113**. With a thick darning-needle make a hole through the paper, and thereby obtain an image on the second screen. Make other holes in the paper, and observe the positions of the images. Fill the paper full of holes and observe the effect. Infer the effect if the screen were all holes. Try it.

Remarks. — The report on this problem should point out clearly what answer the experiment gives to the proposed question.

II. Photometry.

115. Problem. — *To measure the candle-power of a kerosene lamp by means of a Rumford photometer.*

Apparatus. — A lamp, a sperm candle of the size known as "sixes," a white paper screen or preferably a screen of ground glass, and a wooden rod about 1 cm. in diameter and 25 cm. long.

Method. — Support the white screen in a vertical plane. About 10 cm. in front of it support the wooden rod vertically (Fig. 71), and about 30 cm. from the screen place the lighted candle. On the same side of the screen also place the lamp, giving it such a position that it casts a shadow of the rod by the side of that cast by the candle and *equal to it* in darkness. Measure the distance of each light from the shadow on the screen. Then the square of the ratio of the distance of the lamp to that of the candle is the candle-power of the lamp. Why? Make several determinations, varying the distances employed. Ascertain if there is any difference in light-giving power between the broadside of the flame and its edge. Tabulate the results.

Remarks. — The experiment must be conducted in a dark room. If the walls of the room are not painted dead black, neither the lamp nor the candle should be placed near them, since the reflection from them would vitiate the results. If the best results are to be obtained, the only lights in the room should be those under comparison. If work is in progress on adjoining tables, then the light from these tables must be cut off as completely as possible from the screen by means of large sheets of cardboard. The candle should be kept uniformly trimmed, and shielded from air-currents. The lamp should be carefully trimmed, and turned up to its highest point. Diffi-

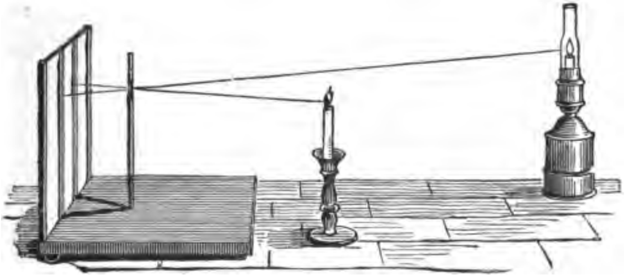

Fig. 71.

culty will be experienced in comparing the shadows, owing to a difference in their color. The full report on this problem should contain a statement of the theory on which it is based.

116. Problem. — *To measure the candle-power of a kerosene lamp by means of a Bunsen photometer.*

Apparatus. — The Bunsen photometer consists of a piece of unsized white paper on which is a grease spot about 3 cm. in diameter. It may be made by dropping a little hot paraffine on the paper and keeping the paper warm till the paraffine has thoroughly soaked into it. A vertical wooden screen like that of ART. **113**, provided with an aperture about 10 cm. square may be used to support this prepared paper by tacking the paper across the aperture with the grease spot at its centre. An excellent method to mount the photometer screen is to insert it within a paper tube, about 10 cm. in diameter and 25 cm. long. The tube should be mounted on a suitable base. The sides of the tube will cut off lights from adjacent tables.

Method. — Place the candle, photometer screen, and lamp in line on the table in a darkened room, arranging them so that the line of the lights is a horizontal one passing through the grease spot on the photometer screen. Now place two plane mirrors to one side of the screen, forming an angle with each other which is bisected by the plane of the screen. Adjust by trial the size of this angle so that by looking in them an image of the grease spot may be seen in each mirror without moving the eye. Adjust the distances of the lights till the two images are as near alike in brightness as possible.

Then measure the distance of each light from the screen and proceed as in Art. **115**.

Remarks. — Two metre sticks fastened end to end on a board will form an excellent scale. The photometer screen should then be placed exactly over the line of meeting. Consult remarks under Art. **115**, and for more accurate methods see Glazebrook and Shaw's "Practical Physics," Chapter XII.

III. Reflection of Light.

117. Problem. — *To investigate the law for the reflection of light.*

Apparatus. — A plane mirror, a protractor, and four darning-needles. The plane mirror may be common looking-glass, but it should be as thin as possible. A piece 8 cm. by 10 cm. cemented to a square block for a support will answer.

Method. — Tack a sheet of manilla paper to the table. Draw a straight line on it, and place the reflecting surface of the mirror in the normal plane containing this line. In front of the mirror set two darning-needles, *A* and *B*, (Fig. 72), normal to the paper. These needles should be five or more centimetres from the mirror and about the same distance apart. Set a third needle, *C*, exactly in

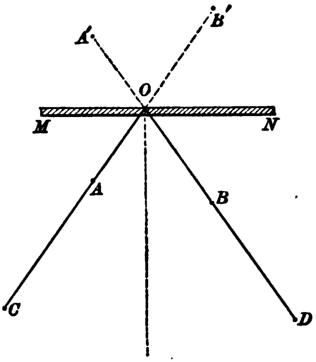

Fig. 72.

line with *A* and the image of *B* seen in the mirror. Set a fourth needle, *D*, exactly in line with *B* and the image of *A*. Remove the mirror and draw fine pencil lines through *A* and *C*, and *B* and *D*. Measure with a protractor (**17**) the angles these lines make with the line of the mirror. If each of these angles is subtracted from 90° we have the angle of incidence and of reflection, since *C* is in line with *A* and the images of both *B* and *D*, and *D* is in line with *B* and the images of both *A* and *C*. Vary the positions of *A* and *D* in repeating the experiment.

Remarks. — The alignments should be made close to the paper to reduce to a minimum the errors due to the needles not being normal to the paper. The needles *C* and *D* should not be placed closer than 10 cm. to *A* and *B* respectively.

Form of Record. — Enter results as follows: —

	ANGLE *COM*.	ANGLE *DON*.	ANG. OF INCI.	ANG. OF REF.
1st trial	....	....	....	....
2d "	....	....	....	....
etc.		etc.		etc.

118. Problem. — *To measure the angle of a glass prism.*

Apparatus. — A prism, straight edge, protractor, and several darning-needles.

Theory. — Let *ABC* (Fig. 73) represent the prism, *HE* and *KE* parallel rays of light incident on *AB* and *AC* respectively, and EN_3 and FN_4 the reflection of these rays from these surfaces. Produce EN_3 and FN_4 till they intersect at

D. Then, by geometry, it can be shown that $EDF = EAF + AED + AFD = EAF + AEH + AFK = 2\ EAF$, that is, *the angle between the reflected rays is twice the angle of the prism.*

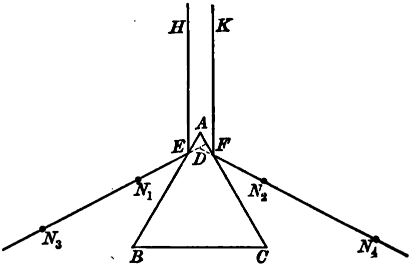

Fig. 73.

Method. — Tack a sheet of manilla paper on the table. Draw on the paper two parallel lines, HE and KF, about 2 cm. apart. Place the prism with the angle to be measured between these lines. In each line set two needles, each normal to the paper. Now place the needles N_1 and N_3 in line with the needles in EH as seen by reflection in the face AB of the prism. In like manner place the needles N_2 and N_4 in line with the needles in FK as seen by reflection in the face AC of the prism. Remove the prism, draw lines through the points marked by the needles, as $N_3\ N_1$, and $N_4\ N_2$. Measure the angle they form at D. Half of this angle is the angle of the prism, as already shown. Obtain the average of several trials.

Remarks. — Great pains must be taken in aligning the needles. If a beam of light is obtainable, then the needles in EH and FK may be omitted, and N_3 may be set exactly in the shadow of N_1, and N_4 in the shadow of N_2, $HEFK$ being the beam of light.

IV. Mirrors.

119. Problem. — *To prove that the image of an object in a plane mirror is situated as far behind the mirror as the object is in front.*

Theory. — It is shown in most elementary text-books on Physics that the law of reflected light applied to the plane mirror leads to the conclusion that there should be formed a virtual image of any object that is in front of the mirror, at a distance behind the mirror equal to that of the object in front. The student should supply the geometrical proof of this part.

Apparatus. — Same as required in ART. **117.**

Method. — Tack a sheet of manilla paper on the table. Draw a straight line on it, and place the mirror in the normal plane containing this line. Set a darning-needle, N_1 (Fig. 74), normally to the paper and about 15 cm. in front of the mirror, *MR*. Set a second one, N_2, in an exact line with the first one and its image, *I*, in the mirror. To one side of these set two more needles, N_3, N_4, so that the line of sight they mark out passes exactly through the image of N_1. Now remove the mirror and draw straight lines through the points marked by the needles, producing

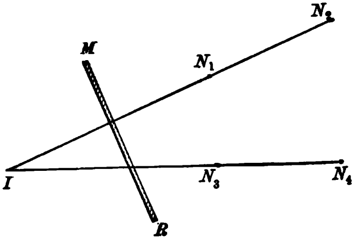

Fig. 74.

them till they intersect. The point of intersection will be the position of the image of N_1. Measure the distance of I and N_1 from MR, recording the former as the distance of the image, and the latter as the distance of the object from the mirror. Make a large number of trials, and tabulate the results.

Remarks. — Do not place the needles closer together than 15 cm. in making the alignments. In setting the needles, keep the line of sight close to the paper. Thick mirrors, on account of the refraction of the glass, will locate I nearer to the mirror than the object, the amount varying with the obliquity of the line N_3N_4. Try it.

120. Problem. — *To measure the focal distance of a concave spherical mirror. First Method.*

Theory. — Let MN (Fig. 75) represent a concave spherical mirror, C its centre of curvature, CD the radius of curvature, represented by r, A an object whose distance AD from the mirror is a, H the image of that object whose distance from the mirror is b, and FD the principal focal distance represented by f. Since CB bisects the angle ABH of the triangle ABH, then by geometry

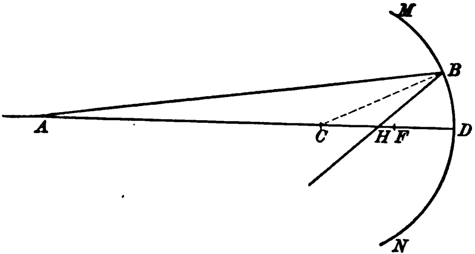

Fig. 75.

$\frac{AB}{BH} = \frac{AC}{CH}$. If B be considered as close to D, then $AB = AD$ and $BH = HD$. Hence, $\frac{AD}{HD} = \frac{AC}{CH}$. But $AD = a$, $HD = b$, $AC = AD - CD = a - r$, and $CH = CD - HD = r - b$. Therefore, $\frac{a}{b} = \frac{a - r}{r - b}$. From which we derive $r = \frac{2ab}{a + b}$, and $f = \frac{1}{2} r = \frac{ab}{a + b}$.

Apparatus. — A concave mirror, a metre stick, a lamp, and two wooden screens. The metre stick should be fastened by screws lengthwise of the middle of a board of the same length and about 20 cm. wide. The screens should be of thin wood about 20 cm. high and 15 cm. wide, attached to a base of the same size, but of thicker wood. When placed on the board, and caused to slide by the side of the metre stick, the screens should be parallel and normal to the board. In one screen cut a circular hole about 3 cm. in diameter and cement across it two threads as diameters at right angles. Support the mirror at the end of the board so that its face is exactly over the end of the metre stick, and its vertex is at the same distance above the board as the aperture in the sliding screen.

Method. — Place the apertured screen at the end of the board with the lamp about 20 cm. behind it to illuminate the aperture. Slide the other screen along the scale till a clear image of the threads of the aperture is formed upon it. Read the distance of each screen from the mirror, recording them as a and b. Correct each distance by adding to each the probable thickness of the glass of the mirror, and compute the focal distance by the formula given above. Make a number of trials, varying the distance of the aperture from the mirror.

Remarks. — This experiment will be more successful if conducted in a dark room.

Form of Record. — Enter results as follows: —

	a.	*b.*	*a.* CORRECTED.	*b.* CORRECTED.	*f.*
1st Trial	74.5 cm.	59.5 cm.	75.5 cm.	60.5 cm.	33.59 cm.
2d "	107.0	47.5	108.0	48.5	33.47
3d "	63.9	69.0	64.9	70.0	33.68
				Mean	33.58
					....

121. Problem. — *To measure the focal distance of a concave spherical mirror. Second Method.*

Theory. — It is shown in Theoretical Physics that, when an object is placed at the centre of curvature of a concave spherical mirror, the image is real, inverted, and located at the centre of curvature.

Apparatus. — A spherical concave mirror, and a darning-needle set normally in a square block of wood. Insert in the eye of the needle a triangularly shaped piece of stiff white paper.

Method. — Support the mirror in a clamp. Place the block carrying the needle at some distance in front of the mirror; place the eye at some distance farther away from the mirror than the needle. On looking toward the mirror an inverted image of the needle will be seen suspended in the air, unless the needle is too close to the mirror. Now adjust the mirror as well as the needle till the point of the paper index coincides with its image. When this is secured can be easily told by noting whether the relative positions of image and object change on moving the eye about. Measure the distance of the point of the paper index from the centre of the mirror. This should be corrected by adding to it the probable thickness of the glass. Half of this distance is the focal distance of the mirror. Make several trials, record in tabular form, and obtain the mean.

122. Problem. — *To measure the focal distance of a convex, spherical mirror.*

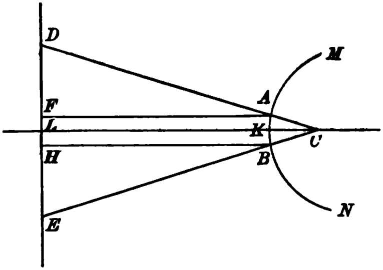

Fig. 76.

Theory. — Let MN (Fig. 76) represent a convex spherical mirror, whose vertex is K. $FABH$ is a beam of light incident upon it through an aperture, FH, in a screen. $DABE$ is the reflected pencil of light diverging from C, the principal focus. Let $FH = AB = a$, $DE = b$, $LK = c$, and $KC = f = \frac{1}{2} R$. By geometry, $\frac{a}{b} = \frac{\frac{1}{2} R}{c + \frac{1}{2} R} = \frac{R}{2c + R}$. Hence, $R = \frac{2ac}{b - a}$.

Apparatus. — A convex mirror, a large screen in which is an aperture about 3 cm. square, and a strong beam of light. Either sunlight[1] or electric light may be used.

Method. — Support the screen so that the light is normal to it, some of it passing through the aperture and striking the mirror, which should be supported parallel to the screen, and 15 to 25 cm. distant from it. If properly adjusted, a square image will be seen on the mirror, and a second one formed by reflection will be seen on the screen. Measure DE, one side of the spot on the screen, FH or AB, the corresponding side of the aperture in the screen, and LK, the distance of the mirror from the screen. Apply the formula given above, and compute the focal distance. Tabulate the results.

Remarks. — There is a large element of uncertainty in this problem on account of the blurred character of the image on the screen.

An Alternative Method. — Support the mirror in a plane normal to the table. Place a black screen at exactly the distance of one metre from the mirror and parallel to it. The screen should be about as wide as the mirror, and have a small aperture exactly opposite the vertex of the mirror. Two narrow strips of white cardboard should be arranged to slide along the screen, one at each end. Fasten a square piece of paper over the middle of the mirror. Now place the eye at the aperture, and slide the strips of cardboard along the screen till their images are seen in the mirror in coincidence with the square ends of the paper on the mirror. Measure the distance between the sliders, as a, the horizontal length of the paper on the mirror as b, and the distance of the screen from the mirror as c. Then $R = \frac{2bc}{a - 2b}$ and $f = \frac{bc}{a - 2b}$.

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[1] To use sunlight for experimental purposes, a porte lumière (145) must be placed in the window to reflect the light into the room. The objections to sunlight are that you cannot always get it when wanted, and but two or three students can work on the problem at the same time. A better arrangement is to place an arc lamp of the focusing type at the centre of a box having the shape of a hexagonal prism. In the faces of this box place lenses whose foci are the arc. Then the light will issue in beams reaching out from the box. It will be found possible, with an arrangement of this kind, to have a dozen or more pupils engaged on this problem at one time.

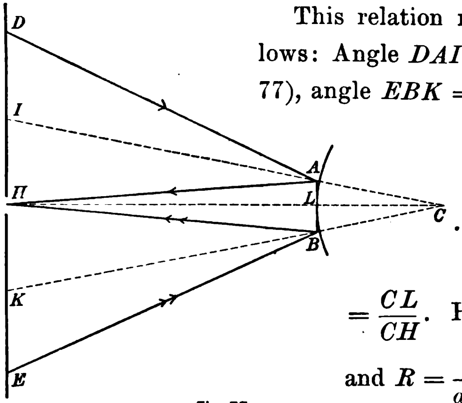

Fig. 77.

This relation maybe proved as follows: Angle DAI = angle HAI (Fig. 77), angle EBK = angle HBK; IK is approximately the half of DE. In the similar triangles ABC and ICK, $\frac{AB}{IK} = \frac{CL}{CH}$. Hence, $\frac{b}{\frac{1}{2}a} = \frac{R}{R + c}$, and $R = \frac{2bc}{a - 2b}$.

123. Problem. — *To determine how a concave spherical mirror disposes of pencils of light.*

Theory. — The student should show, by drawing accurate figures in his note-book, that the law of reflected light applied to the concave spherical mirror yields six distinct cases.

Apparatus. — A concave spherical mirror of *known focal length*, a metre stick, a stout wire 20 cm. long and set in a block, a convex lens of about 50 cm. focal distance, a wooden screen, and a strong beam of sunlight or electric light.

Method. — Support the lens so that the beam of light is incident upon it, and mark the focus with the heavy wire. Between this focus and the lens we have a converging pencil, and beyond this focus we have a diverging pencil. The dust floating in the air of the darkened room will make the above quite apparent. The focus, or wire, is to be regarded as the radiant point or source of the diverging pencil incident on the mirror.

Now give the mirror successively the following positions with respect to this radiant point, and find the position of the focus that the mirror forms of reflected light by the aid of the small screen. When the screen is properly placed, a very distinct image of the illuminated part of the wire marker will be seen upon it.

1st. Place the mirror at a distance from the radiant point as marked by the wire greater than the radius of curvature of the mirror. 2d. Place the mirror at a distance equal to the radius of curvature. 3d. Place the mirror at a distance less than the radius of curvature, but greater than its focal distance. 4th. Place the mirror at a distance equal to its focal distance. 5th. Place the mirror at a distance less than the focal distance. 6th. Place the mirror between the lens and the wire so that a converging pencil is incident upon it.

Remarks. — It will be necessary to turn the mirror a little to one side, so that the reflected light may be received on the screen without the screen's cutting off the light from the mirror.

Form of Record. — Enter results as follows: —

POSITION OF RADIANT POINT.	CHARACTER OF PENCIL.	EFFECT OF MIRROR.	DIST. FROM RADIANT POINT TO MIRROR.	DIST. FROM MIRROR TO CONJ. FOCUS.	POSITION OF CONJ. FOCUS.
Inf. Dist.	Parallel.	Converge.	Infinite.	32 cm.	At prin. focus.
Beyond Cen.	Diverging.	Converge.	70 cm.	59 cm.	Bet. F. and C.
At C.	Diverging.	Converge.	64 cm.	64 cm.	At C.
Bet. F. and C.	Diverging.	Converge.	46 cm.	98 cm.	Beyond C.
etc.	etc.	etc.	etc.	etc.	etc.

Discussion. — The student should point out exactly what proposition is verified by each set of results given above.

124. Problem. — *To determine how a convex spherical mirror disposes of pencils of light.*

This problem should be studied and solved in a manner similar to ART. **123**. It should be noticed that different cases arise under the converging pencil. The following ones will suffice: 1st. When the pencil converges to a point back of the mirror and distant less than the principal focal distance. 2d. When the pencil converges to the principal focus. 3d. When the pencil converges to a point beyond the principal focus.

125. Problem. — *To determine the character of the images of an object given by spherical mirrors.*

Theory. — The student should show from geometrical considerations what kind of images should be given by spherical mirrors. He should also show whether rays from the same point of an object and incident on different parts of a spherical mirror are focused at the same point.

Apparatus. — A convex and a concave mirror of known focal length, a lamp, metre stick, and wooden screen.

Method. — In a dark room place in the order named, a lamp, screen, and concave spherical mirror. Adjust the mirror so that its vertex is about in a horizontal plane with the flame of the lamp. Give the mirror successively the positions described in Art. **123**, and locate the image by means of the screen, noting also its size as compared with the object, and whether erect or inverted.

In like manner study the convex mirror.

Compare as to brightness and sharpness of outline the images when the light is cut off from all but the central portion of the mirror, with that when the whole surface of the mirror is used.

Form of Record. — Art. **123** should suggest a method of entering results in the note-book. The discussion should point out what has been accomplished by each part of the experiment.

V. Refraction of Light.

126. Problem. — *To measure the index of refraction of water.*

Theory. — The index of refraction of a substance equals the quotient of the sine of the angle of incidence by that of the angle of refraction.

Apparatus. — Cover one face of a glass rectangular battery-jar with paper, having cut as large a circle as possible out of the centre of the covering (Fig. 78). Across this circular opening cement two threads marking the horizontal and the vertical diameters respectively. Graduate the margin of the circle to degrees, marking the extremities of the horizontal diameter 0°, and those of the vertical 90°. Provide a strip of cardboard wider and longer than the top of the jar, and cut in it, cross-wise, a slit about 2 mm. wide and 5 cm. long. The remaining faces of the jar should be covered with black paper. A wooden support and a piece of mirror-plate will also be needed.

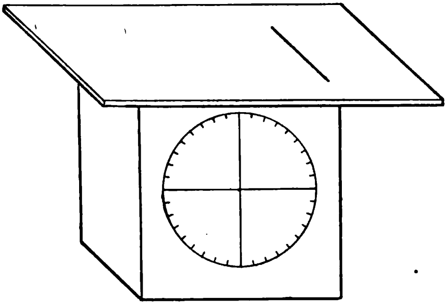
Fig. 78.

Method. — Fill the jar with water exactly to the horizontal diameter of the circle. Place the cardboard containing the slit on top of the jar. Stand the apparatus in the sunlight, adjusting the position of the slit so that a ribbon of light passes through it and strikes the liquid *exactly* back of the centre of the circle. Read off on the circular scale the angle of incidence, and also that of refraction. By means of the plane mirror it will be easy to reflect a beam of light through the slit at a different incident angle. Divide the sine of each angle of incidence by the sine of the corresponding angle of refraction (Table XVIII.). The average of these quotients will be an approximate value of the index of refraction.

Remarks. — In reading the circular scale, be careful to have the line of sight normal to the scale, and to read to the middle of the edge of the ribbon of light. Better results could be obtained by conducting the experiment in a dark room, using a beam of sunlight reflected into the room by a porte lumière App. A. 11, or a beam of light from an electric lantern. Other liquids might be used in the same manner as water.

127. Problem. — *To measure the index of refraction of glass.*

Theory. — If the glass have the form of a triangular prism the angle of which is a, and whose least deviation due to refraction is d, then it can be shown by mathematics that the index of refraction, or i, $= \frac{\sin \frac{1}{2} (a + d)}{\sin \frac{1}{2} a}$.

Apparatus. — A glass prism, protractor, board covered with manilla paper, several darning-needles, and a porte lumière, or electric lantern.

Method. — Close the opening of the porte lumière or electric lantern with a piece of cardboard in which is cut a vertical slit 2 mm. wide and 5 cm. long. In the path of the ribbon of light which passes through the slit place the glass prism, whose refracting angle has been previously measured (**118**). The prism may be supported on a horizontal board covered with manilla paper, and should have its edges parallel to the plane of the ribbon of light, and should intercept the light at such an angle that it suffers the least deviation from its course, a result recognized by slowly turning the prism about its axis till the bright-colored image cast on the opposite wall departs least from the line of light before it suffers refraction. Now set perpendicularly in the board a darning-needle, N_1, to mark the place where the light is incident on the prism (Fig. 79). Set two needles, N_2, N_4, in the shadow cast by N_1. Remove the prism and set a third one, N_3, in the shadow now cast by N_1. Draw lines through the points marked by the needles, as $N_1 N_3$, and $N_2 N_4$. The angle between these lines may be considered as the angle of deviation, and may be measured with a protractor. Find the average of many trials. Substitute the values of the refracting angle and of the angle of deviation in the formula $i = \frac{\sin \frac{1}{2} (a + d)}{\sin \frac{1}{2} a}$.

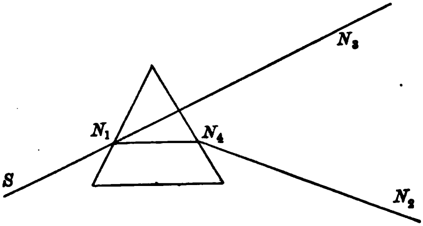

Fig. 79.

If not convenient to use sunlight or electric light, the following method may be pursued. Tack a sheet of paper on the table. Set two darning-needles in the paper to mark a straight line, as S and N_1. Place the prism with one face against the needle N_1. On looking through the prism at the needles N_1 and S, colored images of them will be seen, that of S being quite dim. On turning the prism about its axis the image of S will move. Find that position of the prism which displaces S in the same direction, whether the prism be given a direct or indirect motion. Now set a needle, N_2, in line with the images of N_1 and S as seen through the prism. The angle of deviation will be that between N_1 N_2 and the line SN_1 extended.

VI. Lenses.

128. Problem. — *To measure the principal focal distance of a convex lens. First Method.*

Theory. — Let a (Fig. 80) represent the distance of an object, AB, from a convex lens, b the distance of the image

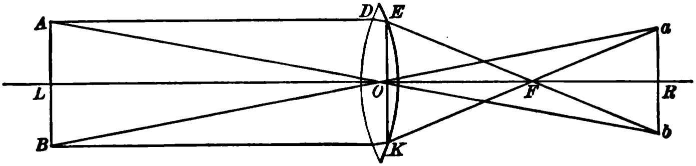

Fig. 80.

ab, and f the focal distance OF. In the similar triangles AOB and aOb, $\frac{AB}{ab} = \frac{LO}{OR}$. In the similar triangles EFK and aFb, $\frac{EK}{ab} = \frac{OF}{FR}$. Since $EK = AB$, then $\frac{LO}{OR} = \frac{OF}{FR}$ and $\frac{a}{b} = \frac{f}{b-f}$. Hence $f = \frac{ab}{a+b}$.

Measure the distance of the cardboard from the lens. This will be the focal distance of the lens. Obtain the mean of several trials.

131. Problem. — *To measure the principal focal distance of a concave lens.*

Theory. — If a beam of light be incident on a concave lens it will issue as a pencil diverging from the principal focus. Let *SC*, *S′D* (Fig. 81) be a beam of light incident on the lens *MN*. Let *AB* be the intersection of the diverging pencil by a plane parallel to the lens. Represent the distance *AB* by *a*, *CD* by *b*, and *EH* by *c*. *CD* may be considered without sensible error as a straight line parallel to *AB*. Then, by geometry, $\frac{FH}{FE} = \frac{AB}{CD}$. $\therefore \frac{f + c}{f} = \frac{a}{b}$ and $f = \frac{bc}{a - b}$.

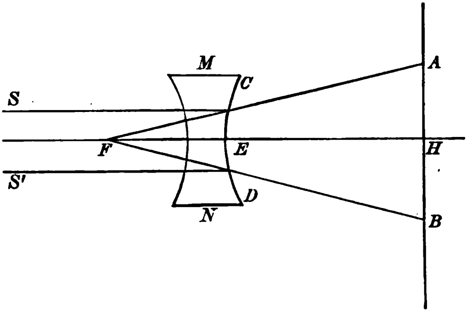

Fig. 81.

Apparatus. — Porte lumière, or electric lantern, concave lens, vertical screen, and metre rod.

Method. — At the centre of a piece of paper as large as the lens cut a square hole 2 cm. on an edge. Support the lens in a vertical plane with this paper covering the face that is turned away from the beam of light. Adjust the paper so that the aperture is over the middle of the lens. Let a beam of light parallel to the principal axis be incident on the lens, and form a square image on a screen parallel to the lens and distant perhaps 50 cm. Measure the diagonal of the aperture, the corresponding diagonal of the image, and the distance between the lens and the screen, and compute f by the above formula. Make several trials with the screen at different distances from the lens.

Make a few trials in which the screen is given such a distance that the diagonal of the image is twice that of the aperture. Then the focal distance equals the distance of the screen from the lens.

Remarks. — The image on the screen will have a poor definition on account of spherical aberration. Hence there will be an uncertainty about the length of the diagonal. The method cannot be depended on for other than approximate results.

132. Problem. — *To ascertain how a convex lens disposes of a pencil of light.*

Theory. — The student should show that the law of refraction applied to the convex lens reveals the existence of several cases of images, which he should state concisely, and illustrate by accurate diagrams.

Apparatus. — Similar to that employed in ART. **123.**

Method. — Proceed as in Art. **123**, except that the lens is between the screen and the source of light. Record the distance from the lens of the point from which the light diverges, and also of the point where it focuses whenever possible. Try the following cases: 1st. With the radiant point distant from the lens more than twice the focal distance. 2d. Twice the focal distance. 3d. Less than twice and more than once. 4th. At the focus. 5th. Less than the focal distance. 6th. Cover the lens with a paper disk in which is cut a ring of holes near the circumference, and determine the distance of the focus from the lens. Again cover the lens with a paper disk in which is a hole over the middle of the lens, and again determine the distance of the focus from the lens. 7th. Find the effect that the lens has on a converging pencil.

Form of Record. — Record and discuss after the manner described in Art. **123**.

133. Problem. — *To ascertain how a concave lens disposes of pencils of light.*

Theory. — The student should show by accurate diagrams that a diverging pencil of light is rendered still more diverging, and that a converging pencil is affected by the degree of convergence.

Apparatus. — Same as used in Art. **123**.

Method. — The diverging pencil should be studied as in Art. **123**. In case of the converging pencil, place the concave lens successively in the following positions: 1st. With its focus *beyond* the point to which the pencil converges. 2d. With its focus *at* the point to which the pencil converges. 3d. With its focus *nearer* the lens than that to which the pencil converges. By moving the screen along the pencil issuing from the lens, the change in character can easily be detected.

134. Problem. — *To ascertain the character of the images formed by lenses.*

Theory. — The student should show by accurate drawings what conditions govern the images that convex and concave lenses give.

Apparatus. — Same as used in ART. **125.**

Method. — *First.* Find the focal distance of the convex lens, if not already known. Arrange in order on the table, the screen, the convex lens supported in a suitable clamp, and the lighted lamp, with their centres in the same horizontal line. Place the light successively at more than twice the focal distance, at twice the focal distance, at less than twice but more than once the focal distance, and, finally, between the focus and the lens, determining in each case, if possible, the position of the screen where the well-defined image of the flame is formed upon it. Compare the image in each case with the object as regards size and position.

Second. Compare the image formed when a lens of small diameter is used, with that when one considerably larger is employed. The apparatus must be adjusted in each case to give an image of the same size as the object.

Third. Compare the definition of the image formed when light is admitted through the whole lens, with that given when the light incident on the outer edge of the lens is cut off by a paper ring placed over it.

Fourth. Substitute a concave lens for the convex, ascertain the character of the image, and determine the effect of varying the distance of the object from the lens.

Form of Record. — **Enter the facts and discuss them in a manner similar to ART. 125.**

APPENDICES.

APPENDIX A.

DIRECTIONS FOR MAKING APPARATUS.

1. To Etch a Scale on Glass. — Thoroughly clean the piece of glass, and coat it evenly with a thin film of beeswax or paraffine. Fasten the glass to the table, and at a distance of about 50 cm. fasten a steel scale. In a wooden bar, about 52 cm. long, 2 cm. wide, and 1 cm. thick, insert at each end, and perpendicular to it, a stout needle-point 2 cm. long (Fig. 82). Place one of the needle-points of the bar on the first division of the scale, and with the other point draw a line in the wax, cutting entirely through it. Then place the needle-point on the second division of the scale, and so on till a scale of sufficient length has been obtained. Every fifth division should be made a little longer than the others, and every tenth division should be longer still. With a sharp-pointed instrument add the proper figures.

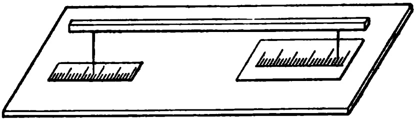

Fig. 82.

Make a rectangular dish out of sheet-lead by turning up the edges. Place in the dish a spoonful of powdered fluor-spar well-moistened with sulphuric acid. Cover the dish with the glass plate, scale-side down. Warm the vessel slightly over a lamp, being careful not to melt the wax, and set aside for a few hours. Remove the wax with benzine. A scale will be found etched in the glass.

2. To Etch a Scale on Brass. — Proceed as in ART. 1, except that the etching is to be done by placing on the surface a piece of blotting-paper wet with nitric acid.

3. To Make a Mirror-scale. — Fasten the piece of mirror-plate on the table, silver-side up. Then, as in ART. 1, cut the scale in the amalgam. Cover the surface with red or black paper. The scale might be etched on the glass face (**1**).

4. Jolly's Balance. — A serviceable one may be made as follows: Provide a stout supporting rod set into a square block for a base. Suspend a spiral spring from an arm projecting from the top. Two or three of these springs should be provided, varying in stiffness. They can be made by winding spring brass wire closely around a cylinder 1 cm. in diameter. Wires varying from No. 20 to No. 30 may be used, according to the sensitiveness required. To the lower end of the spring attach two small scale-pans, one below the other, and about 15 cm. apart. On the standard back of the spring tack a long millimetre scale cut on mirror-plate (**3**). Just above the upper scale-pan fasten a small white bead to serve as an index. The scale-reading is where the line joining the index with its reflection intersects the scale.

The balance may be made to give results in grammes by finding the elongation that a gramme weight will produce, and hence the value of a scale division. This value, multiplied by the elongation in any case, will be weight of the body producing the elongation.

5. A Simple Magnetoscope. — Magnetize a small cylinder of hard steel, about 15 mm. long by 3 mm. in diameter.

Suspend this by a silk fibre in a narrow glass cylinder, about 20 cm. high and 3 cm. in diameter. A brass screw through a cork fitted to the cylinder will serve to support the fibre. Support the magnet horizontally in a stirrup made of thin brass foil. To prevent pendular swinging, connect to the stirrup a second fibre, which is attached to a lead disk resting on the bottom of the cylinder. Adjust the lengths of the fibres to bring the magnet near the centre of the cylinder.

6. A Cheap Electroscope. — Select a Florence flask of about one litre capacity; thoroughly clean and dry it; fit to it a paraffined cork or rubber stopper through which passes a stout brass wire, on the outer end of which is a metal ball about 15 mm. in diameter. File the end of the wire within the flask to a wedge form. Cut out of aluminium foil two strips, each 3 mm. wide and 5 cm. long, and cement them on the faces of the lower end of the wire so that they will hang side by side at the middle of the flask.

7. An Efficient Commutator. — Bore two holes one centimetre deep, and one centimetre apart, in a block of wood. In these pour mercury, connecting each to a binding-post screwed into the block by a short heavy copper wire. The galvanometer is to be connected to the binding-posts, the battery to the mercury-cups by dipping the ends of the wires into them. To reverse the current, it will be necessary simply to cross the battery-wires.

8. Tangent Galvanometer. — Cut out of well-seasoned wood a ring 30 cm. in diameter, and having a cross-section of 3.5 cm. square. Mount this on a circular wooden base provided with levelling-screws. In the outer edge of the ring cut a rectangular groove 2 cm. wide and 2 cm. deep. In this groove wind two turns of heavy copper wire, the ends to be connected to binding-posts on the base. This will give a coil of practically no resistance. Now wind in the same groove, using insulated copper wire No. 26, three other coils of 10, 30, and 90 turns respectively, the ends of each to be connected to its own pair of binding-posts. Fasten across the ring a wooden or brass bar supporting a wooden box 12 cm. in diameter and 5 cm. deep, having a glass cover with a hole 1 mm. in diameter drilled through its centre. Place on the bottom of this box a circular piece of mirror-glass to which is cemented a paper ring graduated to degrees. For a needle, magnetize a piece of watch-spring 15 mm. long, inserting it edgewise into a disk of elder-pith (Fig. 83). Cement to the pith-disk, at right angles to the needle, a pointer of glass thread made by drawing out a piece of glass tubing. Suspend the needle by a silk fibre from a brass pin inserted in the hole in the cover. The needle should hang at the centre of the wooden ring, and within a few millimetres of the scale. When the instrument is levelled, the two ends of the pointer should give the same readings, and reversing the current should not alter the amount of the deflection; if it does, the pointer is either not set at right angles to the needle, or the needle is not properly centred. To eliminate small errors of this kind, average the readings of both ends of the pointer; reverse the current, and average the readings; and finally average these two averages for the correct reading.

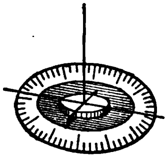
Fig. 83.

9. A Substitute for the Tangent Galvanometer.— Procure a circular wooden box 12 cm. in diameter and 10 cm. deep. Fit to it a glass cover and needle as in Art. 8. Within the box and fastened to the bottom there should be a wooden block 2 cm. thick, on which is wound a flat coil of several layers of No. 24 insulated copper wire. The ends of the wire should be brought through the side of the box and fastened to binding-posts. Cover the coil with a mirror and scale as in ART. 8. This instrument may be used as a tangent galvanometer for deflections as large as 60°.

10. The Wheatstone Slide-bridge. — On a varnished board 1.1 metres long and 15 cm. wide, fasten with brass screws strips of brass 2.5 cm. wide and 3 mm. thick in the manner shown in Fig. 58, the pieces *ME* and *HF* being 10 cm. long, and *A* 90 cm. long. The distance between *E* and *F* is exactly one metre. Solder a stretched German-silver wire (No. 26) between *E* and *F*, parallel to and within 5 mm. of a metre-rod *B*. Add binding-posts to the brass strips, so that connections may be made as shown in the figure. The contact of the galvanometer wire with the German-silver wire may be made by pressing the wire upon it, or by a sliding block in which is a spring which touches the wire on application of pressure.

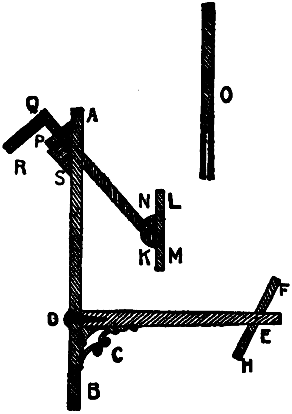

Fig. 84.

11. To make a Porte Lumière. — Procure a piece of pine board as long as the width of the window, and about 60 cm. wide. In it cut a round hole 12 cm. in diameter, the centre of which should be the centre of the line parallel to the edge of the board, and 20 cm. from the bottom. On one face of the board, on opposite sides of the centre of the hole *T* (Figs. 84, 85) and having their inner faces 15 cm. apart, fasten two wooden arms, *DE*, 32 cm. long, supported by iron braces, *C*. Pivot, by screws between their outer ends, a rectangular board, *FH,* 2 cm. thick and 15 cm. square, making the distance, *DE,* 31 cm. Cut a half-round piece, *K,* 5 cm. thick, with a radius of 7 cm., and fasten it by slender screws to the rectangular piece, *LM,* 25 cm. by 15 cm. *QN* is a hard-wood cylinder, 2.5 cm. in diameter; it may be cut from an old broom-handle. In one end, as shown at *O,* cut a slot so that it will clasp the piece *K,* to which it is to be secured by a bolt, around which it is free to turn, with slight friction. *S* is a triangular block, the shape of which is determined by the method illustrated in Fig. 86. On a large sheet of paper lay off the lines *DE* 31 cm., and *DA* 40 cm., forming a right angle at *D,* a point corresponding to the centre of the hole *T.* At *E,* with a protractor, make the angle *DEQ* equal to the latitude of the place. Where *EQ* cuts *DA* is the centre of the hole to be bored for *QN.* The upper angle of the piece *S* is evidently equal to the angle *DEQ.* Cut this piece *S* and fasten it to *AD,* then bore the hole for *QN* perpendicular to the upper face of *S.* *P* is a wooden washer, pinned to *QN,* to serve as a shoulder, and is so placed that *QN* extends through the board far enough to bring the lower edge of *LM* a few centimetres above the top of the hole *T.* *R* is a pin at right angles to *QN,*

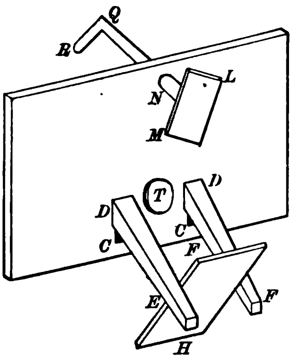

Fig. 85.

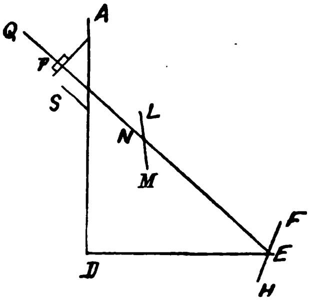

Fig. 86.

for convenience in turning it. On the front of both *LM* and *FH* fasten a good plane mirror, completing the apparatus.

Place this porte lumière in a south window, with the board in a vertical position. Determine by trial the inclination of the mirrors, so that sunlight incident on *LM* is reflected to *FH*, and from it in a horizontal line through *T*. Now, by turning *QN* on its axis, the beam of light can be kept in one place, notwithstanding the continuous change in the position of the sun.

QN is parallel to the polar axis when the porte lumière is in position. The angle between *LM* and *QN* changes with the sun's angular distance from the equator, called its declination. If the declination is represented by d, then the angle between *ML* and *QN* equals $\frac{90 - d}{2}$. It will be found convenient to graduate the piece *K* to degrees to aid in setting *LM*.

12. Laboratory Time-keeper. — In the absence of a clock with electrical connections to give time signals, the following cheap and simple device may be used: —

Procure a brass or iron rod about 1.02 m. long and .5 cm. in diameter, a large iron ball about 8 or 10 cm. in diameter with a hole through it of the diameter of the rod, and a piece of watch-spring. Thread one end of the rod, and fit to it a small nut. Slot the other end, and rivet in it a piece of watch-spring, having it extend about 5 cm. beyond the rod. Support the pendulum from an iron bracket screwed to the side-wall. A slotted bar of brass soldered to the bracket with the end of the watch-spring riveted in the slot will be a simple way to attach the pendulum. Solder to the lower end of the brass rod a piece of platinum wire about 1 mm. in diameter and flattened at the end. This piece need not be over 1.5 cm. long. Provide an electrical contact for the pendulum by a globule of mercury beneath it, through which the platinum strip passes at each vibration. An efficient mercury contact can be made out of a block of wood 2 x 5 x 5 cm. by boring a hole through it parallel to the face of the block, closing one end with an iron binding-post, and the other with an iron machine-screw. A small hole is bored from the face of the block intersecting the first hole and filled with mercury. By turning the machine-screw a globule of mercury can be made to stand up above the block.

Place the pendulum in circuit with a battery and telegraph sounder. Adjust it to seconds by the nut. When placed in vibration, it will continue to swing for two or three hours.

APPENDIX B.

LABORATORY OPERATIONS.

1. Cutting Glass. — To cut small glass tubes, make a deep scratch with a three-cornered file across the tube as it rests on the table; then holding the tube, as shown in Fig. 87, with the scratch turned from you, press suddenly outward with the thumbs, and it will break as desired. To cut off large tubes, flasks, bottles, etc., make a deep scratch with a file, then apply to it either a pointed piece of glowing charcoal, a heated metal rod, or a fine gas-jet. The sudden expansion by heat will generally produce a crack; if not, then touch the heated spot with a wet stick. A crack thus started may be led in any desired direction by keeping the source of heat moving slowly a few millimetres in front of it as it advances. To get a small-pointed gas-flame for the above purpose, connect a glass jet-tube to the gas-supply by a piece of rubber tubing.

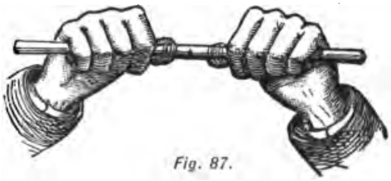

Fig. 87.

An excellent way to cut large glass tubes is to scratch them on the inside. Diamond points attached to stout metal rods can be purchased of apparatus dealers for this purpose. A cheap substitute is to be had in a hard steel wheel pivoted near the end of a rod. A glass tube, thus scratched on the inside, will almost invariably break off on heating it in a Bunsen flame.

Glass plates are readily cut with the common "glass-cutter," an instrument consisting of a hard steel wheel set in the end of a metal rod. Circular glass disks are readily cut by an instrument consisting of a pivoted arm, on which can be clamped a short rod carrying a hard steel wheel or diamond point.

2. Smoothing the End of a Glass Tube. — Hold the end of the tube in the edge of a Bunsen or spirit flame, slowly turning it around. Remove from the flame soon after the flame becomes a bright yellow. In the case of large tubes it will be necessary to smooth them by grinding on a smooth flag-stone wet with water.

3. Bending Tubes. — Warm the tube for several inches each side of the place where the bend is to be, by slowly passing it through the flame; then bring the tube into the gas-flame, slowly rotating it on its axis, heating it evenly for three or four centimetres. When the flame becomes a bright yellow the tube will be soft. Then gently bend the ends from you until the required angle is obtained. Fig. 88 shows how to hold the tube. In bending moderately large tubes a flat flame is preferable.

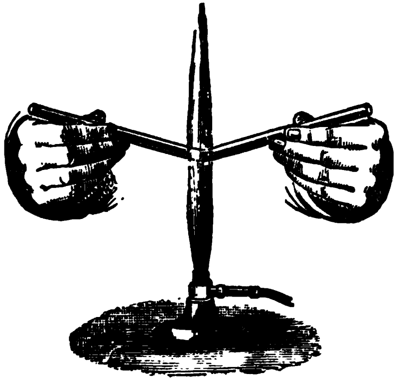

Fig. 88.

Fig. 89 exhibits an attachment for the Bunsen burner to produce such a flame. The fish-tail gas-burner gives an excellent flame for use in bending small tubes. To bend heavy tubes the blow-pipe will be needed.

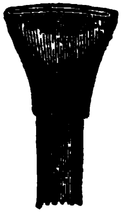

Fig. 89.

4. Closing the End of a Tube. — Soften the tube at the end by holding it in the flame, and then pull the end out with another piece of glass. Keep removing the small tail that is left till it becomes quite small; then heat the end for a few minutes, turning the tube in the fingers. If the tube is held in an inclined position in the flame, the opening will keep contracting till finally it closes up.

5. Drawing out Tubes. — Thoroughly soften the tube uniformly for about three centimetres of its length, then remove from the flame and pull the parts asunder till the diameter is about 1 mm., holding the tube steadily till it cools, to avoid crooking it. Now scratch it with a file at the smallest part and break it in two, smoothing the ends in the flame.

6. Drilling Holes in Glass. — Small holes are quite readily drilled through glass by using a hard drill, wet with a solution of camphor in oil of turpentine. A three-cornered file, with the end broken off, makes a good drill for glass. Large holes may be drilled with a brass tube and emery powder moistened with water. A piece of wood, with a hole in it of the required size, cemented to the glass plate, makes an excellent guide for the drill. The tube can be rotated by the fingers, or if a wooden pully is attached to it, the common drill-stock bow may be used. If the drill is moistened with a paste of fluor-spar and sulphuric acid, the labor of drilling glass is much lessened.

7. Useful Cements. — The following cements will be found very useful both in making and in repairing apparatus:

For cementing wood, leather, metal, or glass to glass, melt at 100° C. one part of gutta-percha and one part of pine-pitch, stirring till homogeneous. Soften the cement by heat when needed for use.

An excellent cement for use about electrical apparatus may be made by melting together the following: — rosin, 7 oz., beeswax, 5 oz., Venetian-red, 4 oz., and Venice turpentine, 1½ oz. Less Venice turpentine will make it harder.

8. Cleaning Mercury. — To the impure mercury add a solution of mercurial nitrate. Stir daily for two or three weeks. Pour off the solution as completely as possible, and dry with the aid of porous paper. Use a shallow glass or porcelain dish for holding the impure mercury.

9. Soldering. — Prepare a soldering fluid by adding scraps of zinc to hydrochloric acid till it refuses to dissolve any more. Wet the surfaces to be joined with this fluid, place between them a few pieces of soft solder, an alloy of lead and tin; then apply heat either by holding the article in a flame, or by directing upon it a blow-pipe flame; on cooling, the surfaces will be firmly joined together.

10. To Amalgamate Battery-zincs. — Immerse the zinc for a few minutes in the following fluid, then remove, and wash in water: — Dissolve 15 ccm. of mercury in a mixture of 170 ccm. of nitric acid and 625 ccm. of hydrochloric acid. The amalgamating fluid should be kept in a glass-stoppered bottle.

11. Battery Fluid for the Carbon and Zinc Battery.

No. 1. — Dissolve 4 oz. of chromic acid in one quart of dilute sulphuric acid, 1 volume of sulphuric acid to 12 of water, and allow the solution to cool and settle.

No. 2. — Dissolve 7 oz. of sodium bichromate in one pint of water, to which is added 3¼ oz. of sulphuric acid.

12. Care of Batteries. — All the connections in a battery must be kept clean and bright, and the zincs well amalgamated. The porous cups must be thoroughly soaked in water before using, and kept in water while the battery is idle. In the Daniell's battery they become clogged in time with copper, and hence useless. They can be renovated by soaking in nitric acid, but it is probably just as cheap to throw them away and substitute new ones. In the carbon battery, where the potassium bichromate solution is used, the carbons become clogged with chrome alum crystals and chromium oxide, greatly increasing the resistance. If the carbons are soaked for an hour in nitric acid, the difficulty will be removed. Chromium oxide is formed in the case of the chromic acid solution, and in time affects the action of the battery.

It often happens that the carbons become detached from the brass clamp in the case of the Grenet battery, and need to be resoldered, a thing easily done if the end of the carbon is first plated with copper. To do this, connect the carbon plate to the negative pole of a Daniell battery, and a strip of copper to the other. Let these dip close together, but not in contact, in a vessel containing a solution of copper sulphate, removing them when the plating covers completely the surface to be soldered. Cover with beeswax the surface not to be plated.

13. Electrical Amalgam. — Take two parts by weight of tin, one part of zinc, and eight parts of mercury. Melt the tin in an iron ladle, add the zinc, and raise it to the melting-point. Now add the mercury, and stir the mixture till it is cool. Apply to the rubber by mixing with the amalgam a little lard.

14. Cleaning Electrical Machines. — To remove dust from electrical machines, use a cloth wet with kerosene oil. The efficiency of both the Frictional and the Holtz machine is frequently largely increased when this is done. Even the old form of Holtz machine seldom fails to work when treated in this way.

APPENDIX C.

PHYSICAL CONSTANTS.

TABLE I.

CAPILLARITY.

HEIGHT at 0° C. to which the liquid will rise in a glass tube 2 mm. in diameter. The height for any temperature between the limits is found by substituting the temperature for *t* in the third column.

SUBSTANCE.	DENSITY.	HEIGHT IN MM.	LIMITS OF TEMPERATURE.
Water,	1.0000	$15.332 - 0.0286t$	0° to 82° C.
Ether,	0.7370	$5.400 - 0.0254t$	− 6° to 35° C.
Olive oil,	0.9150	$7.461 - 0.0105t$	15° to 150° C.
Turpentine,	0.8902	$6.760 - 0.0167t$	17° to 137° C.
Alcohol,	0.8208	$6.050 - 0.0116t - 0.000051t^2$	0° to 75° C.
Sulphuric acid,	1.840	$8.400 - 0.0153t - 0.000094t^2$	12° to 90° C.

TABLE II.

DENSITIES OF VARIOUS SUBSTANCES.

THE following table gives the weight in grammes of 1 ccm. of the substance. These densities should be considered as but approximations, since they vary between quite wide limits in different specimens.

Acetic acid	1.060
Agate	2.615
Alcohol, absolute	0.806
Alcohol, methyl	0.814
Alum	1.724
Aluminium	2.670
Amber	1.078
Antimony, cast	6.720
Apple-tree wood	0.790
Arsenic	8.310
Ash, dry	0.690
Ash, green	0.760
Asphalt	2.500
Basalt	2.950
Beech, dry	0.690 to 0.800
Beeswax	0.964
Bell-metal	8.050
Benzine	0.72 to 0.740
Benzole	0.899
Birch	0.690
Bismuth, cast	9.822
Blood	1.060
Boxwood	1.280
Brass, cast	8.400
Brass, sheet	8.440
Brick	1.6 to 2.000
Bromine	3.187
Butter	0.942
Calcium chloride	2.230
Camphor	0.988
Carbon disulphide	1.293
Carbon dioxide, liquid	0.947
Cedar, American	0.554
Chalk	1.8 to 2.800
Cherry-tree	0.710
Chestnut	0.606
Chloroform	1.525
Clay	1.920
Coal, anthracite	1,26 to 1.800
Coal, bituminous	1.27 to 1.423
Cobalt	8.800
Concrete, ordinary	1.900
Concrete, in cement	2.200
Cork	0.240
Copper, cast	8.830
Copper, sheet	8.878
Deal, Norway	0.689
Diamond	3.530
Earth	1.52 to 2.000
Ebony	1.187
Elder	0.690
Elm	0.579
Elm, Canadian	0.725
Emerald	2.770
Emery	3.900
Ether	0.736
Feldspar	2.600
Fir, spruce	0.512
Fluor-spar	3.200
Galena	7.580
German silver	8.432
Glass, flint	3.0 to 3.600
Glass, crown	2.520
Glass, plate	2.760
Glycerine	1.260
Gold	19.360
Gypsum, crys.	2.310
Granite	2.650
Graphite	2.500
Gun-metal	8.561
Gutta-percha	0.966
Heavy-spar	4.430
Honey	1.450
Human body	0.890
Hydrochloric acid, aq. sol.	1.222
Ice	0.917
Iceland spar	2.723
Iron, bar	7.788
Iron, cast	7.230
Iron, wrought	7.780
India-rubber	0.930
Iodine	4.950
Iron pyrites	5.000
Ivory	1.820
Lard	0.947
Lead, cast	11.360
Lead, sheet	11.400
Lignum vitæ	1.333
Lime, quick	0.843
Limestone	3.180

Logwood	0.913
Magnesium	1.750
Mahogany	0.56 to 0.852
Maple	0.755
Marble	2.720
Mercury	13.596
Milk	1.032
Molasses	1.426
Mortar, average	1.700
Naphtha	0.848
Nitric acid	1.38 to 1.559
Oak, American red	0.850
Oak, American white	0.779
Oak, live, seasoned	1.068
Oak, live, green	1.260
Oil, castor	0.970
Oil, linseed	0.940
Oil, olive	0.915
Oil, turpentine	0.870
Oil, whale	0.923
Paraffine	0.824 to 0.940
Petroleum	0.836
Phosphorus	1.830
Pear-tree	0.660
Pine, red, dry	0.590
Pine, white, dry	0.554
Pine, yellow, dry	0.461
Pine, pitch	0.660
Pitch	1.150
Platinum wire	21.531
Poplar, common	0.389
Porcelain, china	2.380
Potassium	0.865
Quartz	2.650
Rock-salt	2.257
Saltpetre	2.100
Sand, quartz	2.750
Sand, river	1.880
Sand, fine	1.520
Sand, coarse	1.510
Silver, cast	10.424 to 10.511
Slate	2.880
Sodium	0.970
Steel, unhammered	7.816
Sugar, cane	1.593
Sulphur, native	2.033
Sulphuric acid	1.840
Tallow	.9400
Tar	1.015
Tin, cast	7.290
Tourmaline, green	3.150
Vinegar	1.026
Water, at 100° C.	0.958
Walnut	0.680
Water, sea	1.027
Wax, white	0.970
White metal, Babbitt	7.310
Willow	0.585
Zinc, cast	7.000

Gases and vapors at 0° C., barometric pressure of 76 cm.

The following table gives the specific gravity by the substances, air under the standard conditions being taken as the standard. The density can be obtained by multiplying the specific gravity of 0.0012932.

Acetic acid vapor	2.0800
Air	1.0000
Alcohol vapor	1.6138
Ammonia	0.5967
Benzole vapor	2.7290
Carbon monoxide	0.9670
Carbon dioxide	1.5241
Chlorine	2.4501
Coal-gas	0 340 to 0.6500
Cyanogen	1.8060
Ether vapor	2.5630
Hydrochloric acid	1.2780
Hydrogen disulphide	1.1912
Hydrogen	0.0693

Hydriodic acid	4.3737	Nitrogen binoxide	1.0392
Marsh gas	0.5540	Nitrogen monoxide	1.5241
Mercury vapor	6.9207	Oxygen	1.1057
Nitrogen	0.9714	Sulphurous acid	2.2113

TABLE III.

ELECTRICAL RESISTANCE.

LET l represent the length in feet of a circular conductor, d its diameter in thousandths of an inch, and K a constant depending on the material, and so chosen that the resistance of the conductor in ohms at 20° C. is given by the formula $r = Kl \div d^2$. The following table gives the value of K: —

Copper	10.45	Platinum	59.02
German silver	128.29	Silver	9.84
Iron	63.35	Zinc	36.69
Mercury	58.24		

TABLE IV.

APPROXIMATE ELECTRO-MOTIVE FORCE OF PRIMARY BATTERIES.

Daniell, amal. zinc, $H_2SO_4 + 4$ Aq., $CuSO_4$ concentrated sol.	1.079 volts
Daniell, amal. zinc, $H_2SO_4 + 12$ Aq., $CuSO_4$ concentrated sol.	0.978 volt
Daniell, amal. zinc, $H_2SO_4 + 12$ Aq., $CuNO_3$ concentrated sol.	1.000 volt
Daniell, equi-dense solutions of $ZnSO_4$, and $CuSO_4$, plates of pure Zn and Cu.	1.104 volts
Bunsen, amal. zinc, $H_2SO_4 + 12$ Aq., and HNO_3, carbon	1.964 volts
Grove " " " " + 4 Aq., HNO_3, platinum	1.956 volts
Leclanché, zinc in saturated solution of NH_4Cl	1.32 volts
Potassium bichromate	2.00 volts
Edison-Lalande	0.7 volt
Chloride of silver	1.1 volts
Carhart-Clark standard cell	1.44 volts

TABLE V.

Electrical Resistance, Diameter, Cross-Section, etc., of Copper Wire, American Gauge, Temperature 24° C.

Gauge No.	SIZE.		WEIGHT.		RESISTANCE.			Capacity in Amperes.
	Diameter in In.	Area in Sq. In.	Lbs. per 1000 Ft.	Feet per Lb.	Ohms per 1000 Ft.	Feet per Ohm.	Ohms per Lb.	
0000	.4600	.166191	639.60	1.564	0.051	19929.7	.0000785	312
000	.4096	.131790	507.22	1.971	0.063	15804.9	.000125	262
00	.3648	.104590	402.25	2.486	0.080	12534.2	.000198	220
0	.3249	.082932	319.17	3.133	0.101	9945.3	.000315	185
1	.2893	.065733	252.98	3.952	0.127	7882.8	.000501	156
2	.2576	.052130	200.63	4.994	0.160	6251.4	.000799	131
3	.2294	.041339	159.09	6.285	0.202	4957.3	.001268	110
4	.2043	.032784	126.17	7.925	0.254	3931.6	.002016	92.3
5	.1819	.025998	100.05	9.995	0.321	3117.8	.003206	77.6
6	.1620	.020617	79.34	12.604	0.404	2472.4	.005098	65.2
7	.1443	.016349	62.92	15.893	0.509	1960.6	.008106	54.8
8	.1285	.012766	49.90	20.040	0.643	1555.0	.01289	46.1
9	.1144	.010284	39.58	25.265	0.811	1233.3	.02048	38.7
10	.1014	.008153	31.38	31.867	1.023	977.8	.03259	32.5
11	.0907	.006467	24.89	40.176	1.289	775.5	.05181	27.3
12	.0808	.005129	19.74	50.659	1.626	615.02	.08237	23.
13	.0720	.004067	15.65	63.898	2.048	488.25	.13087	19.3
14	.0641	.003147	12.41	80.580	2.585	386.80	.20830	16.2
15	.0571	.002558	9.84	101.626	3.177	306.74	.33133	13.6
16	.0508	.002029	7.81	128.041	4.582	243.25	.52638	11.5
17	.0453	.001609	6.19	161.551	5.183	192.91	.83744	9.6
18	.0403	.001276	4.91	203.666	6.536	152.99	1.3312	8.1
19	.0354	.000984	3.786	264.136	8.477	117.96	2.2392	6.7
20	.0320	.000802	3.086	324.045	10.394	96.21	3.3438	5.7
21	.0285	.000636	2.448	408.497	13.106	76.30	5.3539	4.8

TABLE V. — *Continued.*

Gauge No.	SIZE.		WEIGHT.		RESISTANCE.			Capacity in Amperes.
	Diameter in In.	Area in Sq. In.	Lbs. per 1000 Ft.	Feet per Lb.	Ohms per 1000 Ft.	Feet per Ohm.	Ohms per Lb.	
22	.0253	.000505	1.942	514.933	16.525	60.51	8.5099	4.0
23	.0226	.000400	1.539	649.773	20.842	47.98	13.334	3.4
24	.0201	.000317	1.221	819.001	26.284	38.05	21.524	2.8
25	.0179	.000252	0.967	1034.126	33.135	30.18	34.298	2.4
26	.0159	.000199	0.768	1302.083	41.789	23.93	54.410	2.0
27	.0142	.000158	0.608	1644.737	52.687	18.98	86.657	1.7
28	.0126	.000125	0.484	2066.116	66.445	15.05	137.283	1.4
29	.0113	.000100	0.384	2604.167	83.752	11.94	218.104	1.2
30	.0100	.000079	0.302	3311.258	105.641	9.466	349.805	1.0
31	.0089	.000063	0.239	4184.100	133.191	7.508	557.286	0.84
32	.0079	.000050	0.190	5263.158	168.011	5.952	884.267	0.70
33	.0071	.000039	0.151	6622.517	211.820	4.721	1402.78	0.60
34	.0063	.000031	0.121	8264.463	267.165	3.743	2207.98	0.50
35	.0056	.000025	0.094	10638.30	336.81	2.969	3583.12	0.42
36	.0050	.000020	0.075	13333.33	424.65	2.355	5661.71	0.35
37	.0045	.000016	0.060	16666.66	535.33	1.868	8922.20	0.27
38	.0040	.000012	0.045	22222.22	675.22	1.481	15000.5	0.25
39	.0035	.000010	0.038	26315.79	851.789	1.174	22415 5	0.21
40	.0031	.000008	0.030	33333.33	1074.11	0.931	35803.8	0.17

TABLE VI.

ACCELERATION DUE TO GRAVITY.

Berlin, lat. 52° 30′	981.25 cm.
Greenwich, lat. 51° 29′,	981.17 cm.
Paris, lat. 48° 50′	980.94 cm.
New York, lat. 40° 43′	980.19 cm.
Washington, lat. 38° 54′	980.06 cm.
Lat. of 45°	980.61 cm.
Equator	978.10 cm.
Pole	983.11 cm.

TABLE VII.

RELATIVE THERMAL CONDUCTIVITY.

Bismuth	1.8	Iron	11.9	Silver	100
Brass	23.6	Lead	8.5	Steel	11.6
Copper	73.6	Palladium	6.3	Tin	14.5
Gold	53.2	Platinum	8.4	Zinc	19.0

The above table is due to MM. Wiedemann and Franz, and gives the thermal conductivity of these metals as compared with silver.

TABLE VIII.

BOILING-POINTS OF SUBSTANCES AT BAR. PRESS. 76 CM.

Acetic acid	119° C.	Iodine	200.0
Acetone	56 28	Mercury	350.
Alcohol (amyl)	131.80	Nitrous oxide	—92°.0
Alcohol (ethyl)	78.39	Petroleum	40 to 70.0
Alcohol (methyl)	66.5	Phosphorus	290°.0
Aldehyde	20.78	Sulphur	448.4
Ammonia (liquid)	— 39.00	Sulphuric acid	338.0
Aniline	183.7	Sulphur dioxide	— 8.0
Benzine	90 to 110.00	Turpentine	159.3
Benzole	80.44	Water, distilled	100.0
Bromine	63.00	Water, saturated with NaCl	102.0
Carbon dioxide	—78.00	Water, saturated with KNO_3	116.0
Carbon disulphide	48.00	Water, saturated with $K_2 CO_3$	135.0
Ether	34.90	Water, saturated with $CaCl_2$	179.0

TABLE IX.

COEFFICIENTS OF EXPANSION BETWEEN 0° AND 100° C.

LINEAR.

Aluminium	0.00002221	Copper	0.00001866
Antimony	0.00000980	Ebonite	0.00008420
Bismuth	0.00001330	Glass, tube	0.00000833
Brass	0.00001875	Glass, rod	0.00000861
Bronze	0.00001844	Gold	0.00001460

TABLE IX. — *Continued.*

Graphite	0.00000786	Sandstone, red	0.00001174
Iron, cast	0.00001125	Silver	0.00001943
Iron, wrought	0.00001220	Sulphur	0.00006413
Lead	0.00002799	Steel, tempered	0.00001322
Marble	0.00000786	Steel, untempered	0.00001095
Paraffine	0.00027854	Tin	0.00002296
Pine	0.00000496	Zinc	0.00002976
Platinum	0.00000886		

CUBICAL.

Acetic acid, 0° — 100°	0.00105	Carbon disulp., — 34° — 60°	0.001468
Acetone, 0° — 100°	0.00135	Ether, 0° — 33°	0.0021
Air, const. vol., 0° — 100°	0.003663	Glycerine at 0°	0.000526
Air, const. pres., 0° — 100°	0.003667	Mercury, 0° — 100°	0.000181
Alcohol, amyl, 0° — 124°	0.00109	Olive oil, 0° — 100°	0.00080
Alcohol, ethyl, 0° — 50°	0.001080	Sulphuric acid, 0° — 100°	0.000489
Alcohol, methyl, 0° — 61°	0.001358	Turpentine, — 9° — 106°	0.001050
Benzine, 11° — 81°	0.001385	Water, 4° — 100°	0.000449

TABLE X.

LATENT HEATS OF LIQUEFACTION AND VAPORIZATION.

LIQUEFACTION.

Beeswax	97.22	Silver	21.07
Bismuth	12.64	Sodium nitrate	62.97
Lead	5.37	Spermaceti	82.22
Mercury	2.83	Sulphur	9.37
Phosphorus	5.03	Tin	14.25
Platinum	27.18	Water	79.24
Potassium nitrate	47.37	Zinc	28.13

VAPORIZATION.

Acetic acid	102	Ether	90.4
Alcohol, ethyl	202.4	Mercury	62.0
Alcohol, methyl	264	Sulphur	362.0
Bromine	45.6	Turpentine	74.0
Carbon disulphide	86.7	Water	535.9

TABLE XI.

MELTING-POINTS.

Antimony	425° C.	Mercury	38°.8
Beeswax	62°	Paraffine	38° to 52°
Bismuth	270°	Phosphorus	44°.2
Brass	1020°	Platinum	1775° to 2000°
Butter	33°	Potassium	62°.5
Butter cacao	33°.5	Rose's metal	93°.75
Butter, cocoa	20°.0	Silver	1000°
Copper	1054° to 1200°	Sulphur	115°
German-silver	1093°	Sodium	97°.6
Glass, crown	400°	Stearic acid	69°.9
Gold	1250°	Stearin	60°
Iridium	1950°	Spermaceti	43°.5 to 44°.1
Iron	1500° to 1600°	Tallow, fresh	43°
Japan wax	50°.4 to 51°	Tin	235°
Lard	33°.2	Wax, white	65°
Lead	334°	Wood's metal	60°.5
Margaric acid	59°.9	Zinc	433°

TABLE XII.

SPECIFIC HEAT.

Acetic Acid	0.6589	Ice	0.504
Acetone	0.530	Iron (0° — 100°)	0.1098
Alcohol, ethyl (0° — 50°)	0.615	Lead (19° — 48°)	0.0315
Air	0.2374	Marble	0.2129
Alcohol, methyl (0° — 61°)	0.613	Mercury (0° — 100°)	0.0333
Aluminium (15° — 97°)	0.2122	Nickel (14° — 97°)	0.1217
Antimony (0° — 100°)	0.0507	Nitrogen	0.2438
Beeswax	0.64	Olive oil	0.310
Benzene (11° — 81°)	0.45	Oxygen	0.2175
Bismuth (9° — 102°)	0.0298	Platinum (0° — 100°)	0.0355
Brass, hard (0° — 100°)	0.0858	Silver (0° — 100°)	0.0559
Carbon disulphide (34° — 60°)	0.2206	Salt	0.173
Copper (0° — 100°)	0.0949	Sulphur (15° — 95°)	0.1844
Ether (0° — 33°)	0.517	Steel	0.118
Glass, thermometer (0° — 100°)	0.1770	Tin (0° — 100°)	0.0559
Glycerine (0° — 100°)	0.555	Turpentine (0° — 100°)	0.426
Hydrogen	3.409	Zinc (0° — 100°)	0.0935

TABLE XIII.

INDICES OF REFRACTION.

THE following indices are given for the mean D line: —

Air	1.000294
Aqueous lens, eye	1.357
Alcohol, ethyl	1.361
Benzine	1.49
Canada Balsam	1.54
Carbon disulphide	1.626
Crown glass	1.515
Crystalline lens, eye	1.384
Diamond	2.47 to 2.75
Ether	1.354
Flint glass	1.54 to 1.71
Glycerine	1.47
Ice	1.310
Iceland spar, ordinary ray	1.654
“ “ extra. ray	1.483
Quartz, ordinary ray	1.544
“ extra. ray	1.553
Rock salt	1.550
Ruby	1.779
Vitreous lens, eye	1.339
Water	1.332

TABLE XIV.

MENSURATION RULES.

Area of triangle = base × ½ altitude.

Area of parallelogram = base × altitude.

Area of trapezoid = altitude × ½ sum of parallel sides.

Circumference of circle = diameter × 3.1416 = $\sqrt{\text{area} \div .7854}$.

Diameter of circle = circumference × .3183.

Area of circle = diameter squared × .7854.

Area of ellipse = product of diameters × .7854.

Area of regular polygon = sum of sides × ½ apothem.

Lateral surface of cylinder = circumference base × altitude.

Volume of cylinder = area base × altitude.

Surface of sphere = diameter × circumference.

Volume of sphere = diameter cubed × .5236.

Surface of pyramid } Surface of cone } = circumference base × ½ slant height.

Volume of cone = area base × ⅓ altitude.

Surface of frustum of pyramid or cone = sum of circumference of bases × ½ slant height.

Volume of frustum of pyramid or cone = ⅓ altitude × sum of area of bases and square root of product of these areas.

TABLE XV.

LENGTH OF SECONDS PENDULUM.

Greenwich, latitude	51° 29′	99.413 cm.
Paris, latitude	48° 50′	99.390 cm.
New York, latitude	40° 43′	99.317 cm.
Washington, latitude	38° 54′	99.306 cm.
Latitude	45° 00′	99.356 cm.
Equator		99.103 cm.
Pole		99.610 cm.

TABLE XVI.

VELOCITY OF SOUND AT 0° C.

		Metres.			Metres.
Air	per sec.	332	Hydrogen	per sec.	1269
Ash	"	4668	Iron	"	5127
Brass	"	3318	Lead	"	1228
Caoutchouc	"	60	Maple	"	4106
Carbon monoxide	"	337	Oak	"	3847
Carbon dioxide	"	261	Oxygen	"	317
Cedar	"	5030	Pine	"	3322
Chlorine	"	206	Silver	"	2607
Copper	"	3556	Steel	"	5237
Elm	"	4120	Tallow	"	357
Ether	"	1159	Turpentine at 24°	"	1212
Fir	"	4638	Walnut	"	4601
Glass	"	4526	Water at 8°.1	"	1435
Gold	"	1743	Wax	"	857

TABLE XVII.

TENACITY.

The following table gives the force in kilogrammes required to break a wire of the substance 1 mm. in diameter:—

Copper, drawn	40.3	Lead, drawn	2.07
Copper, annealed	30.54	Lead, annealed	1.80
Iron, drawn	61.10	Platinum, drawn	34.10
Iron, annealed	46.88	Platinum, annealed	23.5

TABLE XVII. — *Continued.*

Silver, drawn	29.00	Steel, cast, drawn	80.00
Silver, annealed	16.02	Steel, cast, annealed	65.75
Steel, drawn	70.00	Tin, drawn	2.45
Steel, annealed	40.00	Tin, annealed	1.70

TABLE XVIII.

TRIGONOMETRICAL FUNCTIONS.

Rule. — To find the sine, tangent, etc., of an angle, find the degrees (integral part) in the column "angle," then proceed horizontally across the page to the column "sine," "tangent," etc., and write down the number found. To this add the product obtained by multiplying the difference between that number and the next one in order by the decimal part of the angle. When the angle exceeds 45°, the column giving the required function is marked at the bottom.

Angle.	Sine.		Tangent.		Cotangent.		Cosine.		Angle.
0	0.000	17	0.000	17			1.000	0	90
1	0.017	18	0.017	18	57.29		1.000	1	89
2	0.035	17	0.035	17	28.64		0.999	0	88
3	0.052	18	0.052	18	19.08		0.999	1	87
4	0.070	17	0.070	17	14.30		0.998	2	86
5	0.087	18	0.087	18	11.43		0.996	1	85
6	0.105	17	0.105	18	9.514		0 995	2	84
7	0.122	17	0.123	18	8.144		0.993	3	83
8	0.139	17	0.141	17	7.115	841	0.990	2	82
9	0.156	18	0.158	18	6.314	643	0.988	3	81
10	0.174	17	0.176	18	5.671	526	0.985	3	80
11	0.191	17	0.194	19	5.145	440	0.982	4	79
12	0.208	17	0.213	18	4.705	374	0.978	4	78
13	0.225	17	0.231	18	4.331	320	0.974	4	77
14	0.242	17	0.249	19	4.011	279	0.970	4	76
15	0.259	17	0.268	19	3.732	245	0.966	5	75
Angle.	Cosine.		Cotangent.		Tangent.		Sine.		Angle.

TABLE XVIII. — *Continued.*

Angle.	**Sine.**		**Tangent.**		**Cotangent.**		**Cosine.**		**Angle.**
16	0.276	16	0.287	19	3.487	216	0.961	5	74
17	0.292	17	0.306	19	3.271	193	0.956	5	73
18	0.309	17	0.325	19	3.078	174	0.951	5	72
19	0.326	16	0.344	20	2.904	157	0.946	6	71
20	0.342	16	0.364	20	2.747	142	0.940	6	70
21	0.358	17	0.384	20	2.605	130	0.934	7	69
22	0.375	16	0.404	20	2.475	119	0.927	6	68
23	0.391	16	0.424	21	2.356	110	0.921	7	67
24	0.407	16	0.445	21	2.246	101	0.914	8	66
25	0.423	15	0.466	22	2.145	95	0.906	7	65
26	0.438	16	0.488	22	2.050	87	0.899	8	64
27	0.454	15	0.510	22	1.963	82	0.891	8	63
28	0.469	16	0.532	22	1.881	77	0.883	8	62
29	0.485	15	0.554	23	1.804	72	0.875	9	61
30	0.500	15	0.577	24	1.732	68	0.866	9	60
31	0.515	15	0.601	24	1.664	64	0.857	9	59
32	0.530	15	0.625	24	1.600	60	0.848	9	58
33	0.545	14	0.649	26	1.540	57	0.839	10	57
34	0.559	15	0.675	25	1.483	55	0.829	10	56
35	0.574	14	0.700	27	1.428	52	0.819	10	55
36	0.588	14	0.727	27	1.376	49	0.809	10	54
37	0.602	14	0.754	27	1.327	47	0.799	11	53
38	0.616	13	0.781	29	1.280	45	0.788	11	52
39	0.629	14	0.810	29	1.235	43	0.777	11	51
40	0.643	13	0.839	30	1.192	42	0.766	11	50
41	0.656	13	0.869	31	1.150	39	0.755	12	49
42	0.669	13	0.900	33	1.111	39	0.743	12	48
43	0.682	13	0.933	33	1.072	36	0.731	12	47
44	0.695	12	0.966	34	1.036	36	0.719	12	46
45	0.707		1.000		1.000		0.707		45
Angle.	**Cosine.**		**Cotangent.**		**Tangent.**		**Sine.**		**Angle.**

TABLE XIX.

SOME USEFUL NUMBERS.

$\pi = 3.1415926.$ $\pi^2 = 9.8696.$ $\frac{1}{\pi} = 0.3183.$

Dyne at New York = .00102 gramme.
Poundal = 13825 dynes.
Erg = .00102 gramme-centimetre.
Foot-pound = .13825 kilogramme-metre.
Foot-poundal = 421390 ergs.
Kilogramme-metre = 7.23308 foot-pounds.

$\sqrt{2} = 1.4142.$
$\sqrt{3} = 1.7320.$
$\sqrt{5} = 2.2361.$
$\sqrt{10} = 3.16228.$

A cubic foot of water at 4° C. weighs 62.425 pounds.
A cubic foot of water at 16⅔° C. weighs 62.321 pounds.
A cubic foot of air at 0° C. weighs 0.080728 pound.
1 ccm. of air at 0° C. 76 cm. weighs 0.0012932 gramme.
1 litre of H. at 0° C., 76 cm. weighs 0.08969 gramme.
Horse-power = 33000 ft. lbs. per minute.
Horse-power = 7.452×10^9 ergs per minute.

1 Paris foot = 0.32484 metre.
1 Paris line = 2.2588 mm.
1 Eng. foot = 0.30480 m.
1 Ger. mile = 7.4204 kilom.
1 Eng. mile = 1.60935 kilom.
1 Rhenish ft. = 0.31385 m.
1 metre = 3.2808 ft.
1 kilometre = 0.62137 mile.
1 litre = 0.26417 gal.
1 litre = 1.0567 quarts.
1 kilogramme = 2.20462 lbs. avoir.

1 gramme = 15.43235 grains.
1 metre = 39.37 in.
1 U. S. gallon = 231 cu. in.
1 avoir. lb. = 0.453592 kilo.
1 ccm. = 0.0610 cu. in.
1 scm. = 0.1550 sq. in.
1 sq. in. = 6.452 scm.
1 cu. in. = 16.387 ccm.
1 cu. ft. = 28.3 litres.
1 cu. ft. = 7.48 gals.

TABLE XX.

REDUCTION RULES.

1 mi. = 8 fur. = 320 rods = 1760 yd. = 5280 ft. = 63360 in.
1 kilo. = 1000 m. = 10000 dcm. = 100000 cm. = 1000000 mm.
1 acre = 4840 sq. yd. = 43560 sq. ft.
1 sq. hkm = 10 sq. dkm. = 100 sq. m. = 1000 sq. dcm. = 10000 scm. = 100000 smm.
1 are = 100 sq. metres.
1 cu. yd. = 27 cu. ft. = 46656 cu. in.
1 cu. metre = 1000 cu. dcm. = 1000 litres = 1000000 ccm.
1 lb. avoir. = 16 oz. = 256 dr. = 7000 gr.
1 oz. avoir. = 437.5 gr.
1 kilo. g. = 1000 g. = 10000 dcg. = 100000 cg. = 1000000 mg.

Feet × .00019 = miles.
Sq. in. × .007 = sq. ft.
Cu. in. × .00058 = cu. ft.
Cu. ft. × 7.48 = U. S. gallons.
Cu. in. × .004329 = U. S. gallons.
U. S. gals. × .13367 = cu. ft.
Cu. ft. of water × 62.4 = lbs. avoir.
Cu. in. of water × .03617 = lbs. avoir.
Metres × 3.2809 = ft.
Ft. × 0.3048 = metres.
Sq. in × 6.451 = scm.
Scm. × 0.155 = sq. in.
Cu. in. × 16.386 = ccm.
Ccm. × .06103 = cu. in.
Litres × 61.027 = cu. in.
Litres × 1.0567 = quarts.
Centilitres × .338 = fluid ounces.
Oz. avoir. × 28.35 = grammes.
Cu. in. × .5541 = liquid ounces.
Lb. × 453.593 = grammes.
Gr. × 15.432 = grains.
Kilog. × 2.2046 = lbs. avoir.
Inches × 2.54 = centimetres.
Cm. × .3937 = inches.

APPENDIX D.

PRICE LIST OF APPARATUS AND MATERIAL.

For the convenience of teachers, the following list of apparatus and material required by this Manual is given. Any article in the list can be furnished by any reputable dealer in physical apparatus at the price affixed.

SIMPLE MEASUREMENTS.

1	Air thermometer bulbs, Exp. 27	$ .25
2	Balance, hand, 7½ inch beam	2.25
3	Balance, specific gravity,	6.00
4	Balance, 9 in. beam, sensibility, .01 g.	9.00
5	Balance, 9 in. beam, sensibility, .03 mg.	25.00
6	Balance, Jolly's	5.00 to 17.00
7	Balance, spring, 48 lbs.	.30
8	Balance, spring, Eng. and met., 8 oz. and 250 g.	.60
9	Blocks, two rectangular, Exp. 15	.20
10	Caliper, sliding with vernier	2.50
11	Caliper, microm., met.	4.50
12	Caliper, outside and inside	.15
13	Caliper, Fig. 7	.50
14	Caliper, Fig. 9	.35
15	Capillary tubes, set of 3,	.10
16	Cross-section paper, per sheet, 24x31 inch.	.20
17	Diag. scale, met., wood,	$ .15
18	Diag. scale, met., ger. sil.	.35
19	Disk, copper, Exp. 28	.50
20	Disk, glass, Exp. 28	.50
21	Dividers, plain, brass	.25
22	Dividers, with pencil-holder, brass	.50
23	Dividers, with pencil-holder, ger. sil.	1.50
24	Dropper-bulb	.05
25	Erdmann's float	.35
26	Graduate, conical, Eng. and met., 8 oz. and 250 c.c.	.90
27	Graduate, conical, Eng. and met., 16 oz. and 500 c.c.	1.30
28	Graduate, cyl., 100 c.c.	.90
29	Metre-rod	.25
30	Protractor, horn, 4 in.	.15
31	V-scale, steel, Exp. 29	1.00
32	Weights, metric, .001 g.–20 g., per set	2.25
33	Weights, met., 1 g.–1 kilo, brass, per set	4.00

MECHANICS.

34	Ball, iron, Exp. 34	$ .10
35	Ball, lead, for pendulum,	.25
36	Barometer, aneroid	8.00
37	Barometer, tube	.35
38	Boyle's law app., simple,	1.75
39	Boyle's law app., Fig. 33,	8.00
40	Bracket, iron, with clamp	.50
41	Car for inclined plane	.90
42	Cyl. for Archimedes Exp.	.30
43	Frame for pendulum	1.50
44	Lever app., Fig. 26	5.00
45	Press. in fluids, Fig. 29	.50
46	Pressure on bottom of vessel, Fig. 32	5.00
47	Pulley, brass	$ .25
48	Siphon, glass	.10
49	Scale-pan, brass, 3 in.	.25
50	Sp. gr. bottle, 25 g., adjusted	.85
51	Sp. gr. bottle, not adjusted	.30
52	Weight, iron, 4 lbs., Exp. 33	.50
53	Whirling machine with attachment	20.00
54	Wheel and axle, Fig. 28,	1.00
55	Wooden bar for flotation	.50
56	Y-tube	.25

HEAT.

57	Beaker, copper, 1 litre	$1.00
58	Beaker, glass, 1 litre	.24
59	Beaker, glass, ½ litre	.18
60	Coefficient of expansion app., Fig. 43	2.50
61	Coefficient of expansion app., fluids	.75
62	Conduction app., tin	1.50
63	Conduction app., copper	2.00
64	Cube of wood with ball,	.30
65	Lemonade shaker, tin	.20
66	Metric screw for exp. app. (separate)	$1.50
67	Newton's law of cooling app.	.60
68	Test-tube, wide	.08
69	Thermometer, — 15° C. to 200° C., paper scale,	1.00
70	Thermometer, — 15° C. to 200° C., glass	1.70
71	Water-trap for Exp. 74	.15

MAGNETISM AND ELECTRICITY.

72	Ampere app., Fig. 60	$1.75
73	Commutator, two-hole	.50
74	Commutator, four-hole	.75
75	Compass	.30
76	Connector	.10
77	Cell, Daniell	1.50
78	Cell, Leclanche	.65
79	Cell, Taylor	2.00
80	Current induction app.	$4.00
81	Electroscope	.75
82	Glass rods, per pair	.40
83	Galvan. block, Fig. 51	.50
84	Galvanometer tangent, Fig. 53	10.00
85	Galvan. tangent, sub.	3.25

MAGNETISM AND ELECTRICITY— Continued.

86	Galvanometer, with commutator	$3.75
87	Galvanometer, astatic	3.25
88	Magnet, bar, 6 in.	.30
89	Magnet, horseshoe, 3 in.	.18
90	Mag. needle, mounted	.60
91	Magnetoscope	1.50
92	Proof-plane	.15
93	Res. box, 1 to 100 ohms	6.00
94	Res. box, 1 to 1000 ohms	30.00
95	Solenoid	$1.25
96	Sealing-wax, two sticks,	.20
97	Sheets of paper, wood, iron, glass, etc.	.50
98	Strips of zinc, copper, etc., for Exps. 84, 86, each	.05
99	Stand, Fig. 50	.30
100	Telegraph key	1.50
101	Wheatstone bridge	3.00

SOUND.

102	Clamp, iron	$0.40
103	Glass tubes, Exp. 102, per set	1.25
104	Glass tubes, Exp. 103, per set	1.00
105	Glass tube, Exp. 104	1.00
106	Interference app., Fig. 67	1.00
107	Kundt's app., Fig. 65	2.00
108	Manometric flame app.	2.00
109	Motor, electric	3.00
110	Motor, with speed indicator	$5.50
111	Siren disk	.25
112	Sonometer	4.25
113	Tuning-fork, C = 256,	1.00
114	Tuning-fork, A = 435,	.20
115	Tuning-fork, C′ = 512,	.50
116	Tuning-forks, set of 4,	5.00
117	Tin tubes for reflection of sound	2.00
118	Wooden bars for vibration, per set	.60

LIGHT.

119	Candle, sperm	$0.10
120	Mirror, plane, 4x6 in.	.20
121	Mirror, concave and convex, 4 in.	3.00
122	Lens, convex, 2 in. diam.	.60
123	Lens, convex, 3 in. diam.	.75
124	Lens, concave, same prices.	
125	Porte Lumière, with lenses	$12.00
126	Photometer disk	.10
127	Prism, crown	.40
128	Refraction app., Exp. 126	.75
128*a*	Spy Glass	2.00
129	Wood screens, per set	.50

GENERAL APPARATUS.

130	Alcohol lamp	$ .25
131	Bunsen burner	.45
132	Funnel, glass, 4 in.	.12
133	Florence flask, 1 oz.	.10
134	Florence flask, 16 oz.	.20
135	Florence flask, 32 oz.	.25
136	Pinchcock, Fig. 19	$ .30
137	Stand, iron, 2 rings	.45
138	Stand, wood, universal	1.25
139	Sand pan	.20
140	Tumbler, common	.05

MATERIAL.

141	Asbestos paper, per sheet	$ .20
142	Ammon. chloride, per lb.	.20
143	Beeswax, per lb.	.50
144	Binding-posts	.10
145	Cardboard, per sheet	.15
146	Cement, gutta percha, per oz.	.10
147	Cement, insulating, per lb.	.20
148	Copper sulphate, per lb.	.10
149	Corks, ¼ in. to 2 in., per gross	1.20
150	Chromic acid, com., per lb.	.50
151	Iron filings, per lb.	.10
152	Mercury, per lb.	.80
153	Paraffine, per lb.	.25
154	Sodium nitrate, com., per lb.	.12
155	Sulphuric acid, com., per lb.	.04
156	Stoppers, rubber, per oz.	.20
157	Tubing, glass, capillary, per oz.	$ .10
158	Tubing, glass, under 1 in., per lb.	.50
159	Tubing, glass, over 1 in., per lb.	.75
160	Tubing, rubber, per ft., ¼ in.	.09
161	Tubing, rubber, 1 in. diam., per ft.	.30
162	Wire, brass, spring, No. 20, per oz.	.05
163	Wire, brass, spring, No. 30, per oz.	.08
164	Wire, copper, naked, No. 16, per lb.	.40
165	Wire, copper, covered, No. 20. per lb.	.50
166	Wire, copper, covered, No. 24, per lb.	.90
167	Wire, Ger. sil., naked, No. 24, per lb.	1.15
168	Wire, iron, naked, No. 16, per lb.	.15
169	Zinc sulphate, com., per lb.	.15

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